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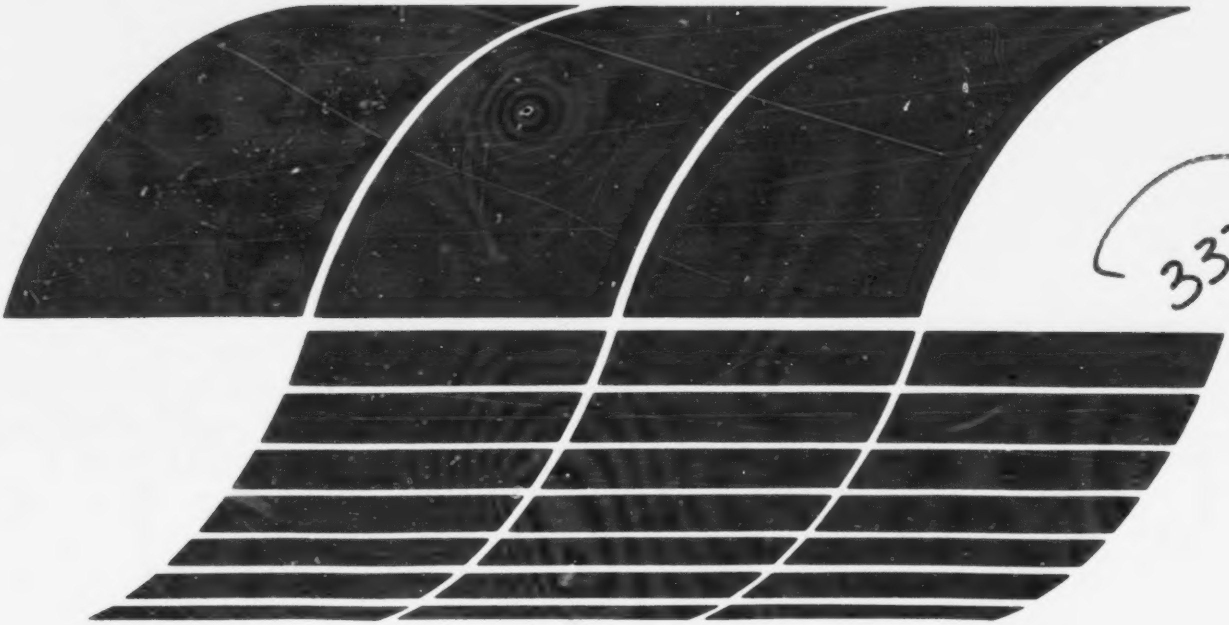
Volume V.

Disposal of FGC Wastes

Interagency
Energy/Environment
R&D Program Report



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Waste and Water Management for Conventional Coal Combustion Assessment Report - 1979
Volume V. Disposal of FGC Wastes

by

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CONVERSION FACTORS

English/American Units	Metric Equivalent
Length:	
1 inch	2.540 centimeters
1 foot	0.3048 meters
1 fathom	1.829 meters
1 mile (statute)	1.609 kilometers
1 mile (nautical)	1.852 kilometers
Area:	
1 square foot	0.0929 square meters
1 acre	4,047 square meters
Volume:	
1 cubic foot	28.316 liters
1 cubic yard	0.7641 cubic meters
1 gallon	3.785 liters
1 barrel (42 gals)	0.1589 cu. meters
Weight/Mass:	
1 pound	0.4536 kilograms
1 ton (short)	0.9072 metric tons
Pressure:	
1 atmosphere (Normal)	101,325 pascal
1 pound per square inch	0.07031 kilograms per square centimeter
1 pound per square inch	6894 pascal
Concentration:	
1 part per million (weight)	1 milligram per liter
Speed:	
1 knot	1.853 kilometers per hour
Energy/Power:	
1 British Thermal Unit	1,054.8 joules
1 megawatt	3.600×10^9 joules per hour
1 kilowatt hour	3.60×10^6 joules
Temperature:	
1 degree Fahrenheit	5/9 degree Centigrade

GLOSSARY

Cementitious: A chemically precipitated binding of particles resulting in the formation of a solid mass.

Fixation: The process of putting into a stable or unalterable form.

Impoundment: Reservoir, pond, or area used to retain, confine, or accumulate a fluid material.

Leachate: Soluble constituents removed from a substance by the action of a percolating liquid.

Leaching Agent: A material used to percolate through something that results in the leaching of soluble constituents.

Pozzolan: A siliceous or aluminosiliceous material that in itself possess little or no cementitious value but that in finely divided form and in the presence of moisture will react with alkali or alkaline earth hydroxide to form compounds possessing cementitious properties.

Pozzolanic Reaction: A reaction producing a pozzolanic product.

Stabilization: Making stable by physical or chemical treatment.

ABBREVIATIONS

BOD	biochemical oxygen demand
Btu	British thermal unit
cc	cubic centimeter
cm	centimeter
COD	chemical oxygen demand
°C	degrees Centigrade (Celcius)
°F	degrees Fahrenheit
ESP	electrostatic precipitator
FGC	flue gas cleaning
FGD	flue gas desulfurization
ft	feet
g	gram
gal	gallon
gpd	gallons per day
gpm	gallons per minute
hp	horsepower
hr	hour
in.	inch
j	joule
j/s	joule per second
k	thousand
kg	kilogram
kCal	kilocalorie
km	kilometer
kw	kilowatt
kwh	kilowatthour
ℓ or lit	liter
lb	pound
M	million
m^2	square meter
m^3	cubic meter
mg	milligram
MGD	million gallons per day
MW	megawatt
MWe	megawatt electric
MWH	megawatt hour
μg	microgram
mil	milliliter
min	minute
ppm	parts per million
psi	pounds per square inch
psia	pounds per square inch absolute
scf/m	standard cubic feet per minute
sec	second
TDS	total dissolved solids
TOS	total oxidizable sulfur
TSS	total suspended solids
tpy	tons per year
yr	year

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1.0 INTRODUCTION

1.1 Purpose and Content

As coal utilization in utilities and large industrial boilers increases, the quantity of flue gas cleaning (FGC) wastes, particularly those associated with flue gas desulfurization (FGD), will increase dramatically. The preponderant part of these FGC wastes will be sent for disposal. Over the long term, utilization is expected to grow but at a slower rate than that of FGC waste generation. Projections of coal ash and FGD wastes through 2000 were provided in Volume 3.

In the past, utilities operating FGC systems have typically disposed of wastes by storage in ponds, often without provision for control of overflows or seepage into groundwater. However, several factors will dramatically influence disposal options in the coming years.

a. An increase in coal-fired capacity in the United States. In 1976 the total U.S. coal-fired electric utility generating capacity was estimated at over 191,000 MW in 399 plants [1]. The estimated capacity is expected to increase by 1986 to over 326,000 MW [2]. Use of coal in large industrial boilers (+25 MW equivalent or larger) is likely to further increase the total coal-fired capacity [3,4].

b. A major increase in the application of scrubber technology by utilities and a consequent increase in FGD waste generation. At present, over 16,000 MW of generating capacity at some thirty plants utilize FGD systems. As of September 1978, over 59,000 MW of capacity have been committed [5]. Future increases are likely to be even more dramatic.

c. Advances in stabilization technology for FGD wastes which permit landfill disposal of partially dewatered solids instead of ponding of difficult to handle sludges. In the future, disposal of wastes in managed fills is likely to be encouraged. In many cases this will require stabilization prior to disposal.

d. Regulatory developments including the Clean Air Act of 1977 and the Resource Conversation & Recovery Act of 1976 (RCRA). The recent issuance of proposed guidelines provides impetus to environmentally sound disposal of FGC wastes [6]. New Source Performance Standards (NSPS) for criteria pollutants are now under review by the EPA and may be significantly tightened.

Thus, disposal of FGC wastes will require major and continuing focus on potential environmental impacts.

This is the fifth in a five-volume report assessing technology for the control of waste and water pollution from combustion sources. This volume reports on the status of FGC waste disposal including both current commercial practice and ongoing R&D programs. The focus of this volume includes the technical, economic, regulatory and environmental aspects of ongoing technology development and commercialization of FGC waste disposal. FGC wastes considered in this report include FGD wastes primarily from non-recovery systems.

The primary focus of this report is on coal-fired power plants; however, many of the characteristics discussed would also apply to wastes from oil-fired boilers. Coal-fired power plants generate the maximum range of waste types and usually the greatest quantity. Thus, they can serve as the logical focus for assessing environmental and technological problems relating to the disposal and utilization of waste materials.

A coal-fired power plant produces two broad categories of coal-related wastes:

- Coal ash, which includes both fly ash and bottom ash (or boiler slag), and
- Flue gas desulfurization (FGD) wastes from the control of sulfur dioxide emissions.

Together, fly ash and FGD wastes are generally referred to as flue gas cleaning (FGC) wastes. In many cases, fly ash and SO_2 emissions are separately controlled and represent separate waste streams. In other cases, fly ash and FGD wastes are combined in a single stream, either through admixture of these wastes or through simultaneous collection of fly ash and SO_2. This review of FGC waste includes coal ash, FGD wastes, and their combination both as produced directly from FGC systems as well as wastes processed for disposal.

The review and assessment has involved two separate efforts as described below:

1. Review of the data and information available as of February 1979 on the disposal of FGC wastes. The review is based upon published reports and documents as well as contacts with private companies and other organizations engaged in FGC technology development or involved in the design and operation of FGC systems and waste disposal facilities. Much of the information has been drawn from the waste disposal and characterization studies and technology development/demonstration programs sponsored by the Environmental Protection Agency (EPA) and the Electric Power Research Institute (EPRI).
2. Based upon the review of the data and assessment of ongoing work in waste disposal, identification of data and information gaps relating to waste properties and the development of recommendations for potential EPA initiatives to assist in covering these gaps. The principal purpose of this effort is to ensure that, ultimately, adequate data will be available to permit reasonable assessment of the impacts associated with the disposal and/or utilization of FGC wastes.

Throughout this work, emphasis has been placed upon wastes produced by commercially demonstrated technologies and, where data are available, by technologies in advanced stages of development that are likely to achieve commercialization in the United States in the near future. In terms of FGD wastes, consideration is limited to non-recovery FGD systems with focus on those producing solid wastes (rather than liquid wastes). There are very few recovery systems in operation or under construction in the United States, and these generally produce a small quantity of waste in comparison to non-recovery systems.

1.2 Report Organization

Complete assessment of FGC waste disposal is site- and system-specific. With that understanding, this volume presents a broad overview on the following subjects to provide a generic baseline for environmental assessment:

- Description of disposal options studied or practiced today,
- Definition of potential impact issues,
- Assessment of environmental impacts,
- Review of monitoring considerations, and
- Review of FGC waste disposal economics.

2.0 DISPOSAL OF FGC WASTES

2.1 Disposal Options

2.1.1 Overview on FGC Technology and Waste Properties

Coal-fired industrial and utility boilers generate two types of combustion-related wastes:

- Coal ash, including fly ash and bottom ash (or boiler slag), and
- FGD wastes from the control of SO_2 emissions.

The technology of ash collection and flue gas desulfurization (FGD), the characteristics of the wastes produced, and projections on waste generation were discussed in Volume 3. This chapter provides a review of disposal options both current and potential. Emphasis is placed on fly ash and nonrecovery FGD process wastes since these will be the principal products in the next few years.

Detailed physical and chemical characterization of FGC wastes is provided in Volume 3. Some aspects of FGC wastes will be considered here to place disposal options in perspective.

2.1.1.1 Coal Ash

The total amount of coal ash produced is a function of the ash content of the coal. The partitioning of coal ash between fly ash and bottom ash (or boiler slag) is dependent on the type of boiler and its general operating condition. Standard pulverized-coal-fired boilers typically produce about 80-90% of the ash as fly ash. In cyclone-fired boilers, frequently used to burn lignite, the fly ash fraction is usually less; in some cases, bottom ash constitutes the majority of the total ash generated.

Collection of bottom ash (or boiler slag) does not involve systems outside the boiler itself. The key technology issue is the handling of bottom ash. Fly ash, however, is a major source of particulate emissions and, with regulatory requirements, has required major collection systems. Control of particulate emissions from pulverized-coal-fired steam generators is rapidly becoming a significant factor in the siting and public acceptability of coal-burning power plants. The particulate emissions limit under current NSPS set by the EPA for large, new coal-fired boilers is 0.043 grams/10^6 joules (0.1 lb/10^6 Btu). Some states have requirements more restrictive than this. Furthermore, the NSPS are now under review and are expected to be tightened significantly. Tightening regulatory posture indicates the following:

- For reliable service in new large systems, fly ash will be collected separately from wet scrubbing-based FGD systems. In the past, simultaneous collection of both fly ash and SO_x has been practiced. If dry sorbent FGD systems are used, simultaneous collection will be practiced.
- Fly ash collection will be based primarily on electrostatic precipitators (ESP's) or fabric filters. Mechanical collection may be employed only to supplement the above two types of particulate collectors.

The chemical composition of coal ash (bottom ash, fly ash, and slag) varies widely in concentrations of both major and minor constituents. The principal factor affecting the variation in the composition is the variability in the mineralogy of the coal. However, differences in composition can exist between fly ash and bottom ash (or boiler slag) generated from the same coal because of differences in the degree of pulverization of the coal prior to firing, the type of boiler in which the coal is fired, and the boiler operating parameters and combustion efficiency. Regardless of the type of ash (either fly ash or bottom ash), more than 80% of the total weight of the ash is usually made up of silica, alumina, iron oxide, and calcium oxide. It should be noted that the compositional breakdown usually shown in the literature (including Volume 3) reflects only the elemental breakdown of the constituents reported as their oxides and not necessarily the actual compounds present.

While the major constituents of bottom ash and fly ash are generally similar, there is usually an enrichment of trace elements in the fly ash as compared with the bottom ash based upon the total quantity of trace elements in the coal fired. A few of the elements originally present in the coal (notably sulfur, mercury, and chlorine) are almost completely volatilized and leave the boiler as gaseous species which are not collected downstream in dry ash collection equipment. However, these can be collected in wet scrubber systems.

Up to 10% of fly ash can be water-soluble, so the potential exists for release of contaminants through leaching. The principal soluble species are usually calcium, magnesium, sodium, potassium, sulfate, and chloride. Leachates resulting from ash are usually alkaline due to the presence of calcium oxide and other alkaline species, although some ashes have been found to be inherently neutral or even acidic.

The physical properties of fly ash vary with the type of coal fired, the boiler operating conditions, and the type of fly ash collector employed. A mechanical collector, which generally removes only the heaviest fly ash fraction, produces a relatively coarse material with the consistency of a fine sand. In contrast, the ash removed in an electrostatic precipitator is usually finer, with a silt-like grading. The range of specific gravities of fly ash depends upon particle size distribution and fly ash composition; however, specific gravities typically range from approximately 1.9 to 2.7. Usually a small portion of the fly ash consists of cenospheres (hollow spheres) which have an apparent density less than water. Bulk densities of fly ash, because of the variations in specific gravity and particle size distribution, vary greatly; although, a typical range for fly ash compacted at optimum dry density would be 1.1-1.79/cm^3 (70-105 lb/ft^3).

An important property of coal fly ash is its pozzolanic activity. Pozzolanic activity refers to the ability of fly ash to aggregate and harden when moistened and compacted due to reactions with lime either present in the ash or admixed with the ash. Because the degree of pozzolanic activity can vary greatly, there can be considerable variation in the engineering and structural properties of fly ash. Ashes from most lignite and some subbituminous coals, for example, have relatively high calcium levels (>10% measured as calcium oxide) and, as such, usually exhibit significant self-hardening properties. However, in general, unstabilized fly ash (that to which lime has not been added intentionally) usually exhibits engineering properties similar to soils of equivalent particle size distributions. Permeabilities of compacted fly ash samples generally range from 5×10^{-4} cm/sec to 5×10^{-5} cm/sec. (See Volume 3, Reference 70,82,83.) Stabilization of pozzolanic fly ashes with lime can result in significant increases in compressive strength and decreases in permeability (depending upon the amount of lime, the water content, curing time, and degree of compaction).

Bottom ash can be collected either dry or in a molten state, in which case it is generally referred to as boiler slag. Dry-collected bottom ash is heavier than fly ash, with a larger particle size distribution. Since it has a similar chemical composition to that of fly ash, it behaves similarly, although pozzolanic activity is usually somewhat less in bottom ash.

Boiler slag is a black, glassy substance created by water quenching of the molten ash. It is composed chiefly of angular or rod-like particles, with a particle size distribution ranging from fine gravel to sand. Boiler slag is porous, although not of so great a porosity as dry bottom ash. It is generally less reactive in terms of its pozzolanic properties than either dry bottom ash or fly ash. Because of the similarities between bottom and fly ashes, they are generally grouped together for environmental impact assessments.

2.1.1.2 FGD Wastes

FGD systems are generally categorized into two groups:

- Nonrecovery or throwaway systems which produce a solid or liquid waste with little market value at present, and
- Recovery systems that produce elemental sulfur or sulfuric acid as a byproduct for sale.

At present, the overwhelming majority of FGD systems for controlling emissions from industrial and utility boilers utilize some form of nonrecovery system. Over 90% of the 59,000 MW committed to FGD systems involve nonrecovery processes [5]. This dominance of nonrecovery processes is expected to continue over the next ten years.

Commercially available nonrecovery processes can be conveniently subdivided into two groups according to the form of the waste materials produced--those which convert the SO_2 into a solid waste and those which produce a liquid waste. Nonrecovery systems can also be classified according to the manner in which the flue gas is contacted with the SO_2 sorbent--i.e., wet scrubbing processes versus dry processes.

All nonrecovery systems now in commercial operation on utility and industrial boilers are wet processes involving contact of the gases with aqueous slurries or solutions of absorbents. Although most nonrecovery systems can withstand relatively high levels of particulate and trace contaminants and many in the past have been designed for simultaneous SO_2 and particulate control, most systems being installed today on utility boilers are downstream from high efficiency electrostatic precipitators in order to ensure more reliable service. The notable exceptions are systems designed to utilize alkalinity in the fly ash for all or part of the SO_2 removal. These frequently incorporate simultaneous fly ash and SO_2 control.

Dry processes have not yet been demonstrated commercially on a utility scale in the United States. However, a number of different approaches have been investigated, including dry injection of sorbents into the boiler and flue gas and the use of spray dryers. All of these involve simultaneous SO_2 and particulate control, and all produce a dry waste material. The most promising approach at present employs spray dryers for contacting the flue gas with slurries (or solutions) of calcium hydroxide or sodium carbonate/bicarbonate. Three such systems have been contracted for application to utility-scale boilers.

Solid Wastes

The four basic types of nonrecovery systems producing solid wastes are:

- Direct lime scrubbing,
- Direct limestone scrubbing,
- Alkaline fly ash scrubbing, and
- Double (dual) alkali.

The first three of these utilize slurries of lime, limestone, or ash to contact the flue gases and produce slurries containing 5-20 wt% solids which are either discharged directly or partially dewatered and possibly further processed prior to discharge. All three of these are commercially demonstrated technologies. The fourth, the double alkali process, is a second generation technology which has been applied successfully to industrial-scale boilers but is only now reaching commercial demonstration on utility boilers. Double alkali processes utilize solutions of sodium salts for SO_2 removal, which are then regenerated using lime to produce a waste solid that is discharged as a filter cake.

In addition, dry sorbent based FGD systems are also likely to be in commercial use by the early 1980's. These will be based on lime, sodium salts or other sorbent and will produce dry solid wastes. To date, the extent of focus on utilization of such dry sorbent wastes has been minimal.

The quantity and composition of ash-free FGD wastes are dependent upon a number of factors including: coal characteristics (most importantly, its sulfur content and heating value); SO_2 emissions regulations; the type of boiler and its operating conditions; and the type of FGD system and its operating conditions. In general, the quantity of dry, ash-free FGD waste produced varies from about 2.0 to about 3.5 times the quantity of SO_2 removed from the flue gas. Hence, a typical utility boiler operating at a 70% load factor could produce anywhere from 50 to 500 tons of dry, ash-free solids annually per megawatt of boiler capacity.

The principal substances making up the solid phase of FGD wastes are calcium-sulfur salts (calcium sulfite and/or calcium sulfate) along with varying amounts of calcium carbonate, unreacted lime, inerts and/or fly ash. In wet processes the ratio of calcium sulfite to calcium sulfate is a key design and operating parameter, especially for direct scrubbing systems since it can affect not only the scale potential of the system but also the waste solids properties. The relative amounts of calcium sulfite and sulfate present depend principally upon the extent to which oxidation occurs within the system. Oxidation is generally highest in systems installed on boilers burning low sulfur coal or in systems where oxidation is intentionally promoted. In most medium to high sulfur coal applications, oxidation of sulfite to sulfate in the scrubber system amounts to only 10-30%, and calcium sulfite is the predominant material in the waste. When the sulfate content of the waste solids is low, calcium sulfate usually is present as the hemihydrate salt ($CaSO_4 \cdot 1/2H_2O$). At higher calcium sulfate levels, gypsum ($CaSO_4 \cdot 2H_2O$) becomes the predominant form of calcium sulfate. At very high levels of oxidation (greater than 90% oxidation of the SO_2 removed) all of the calcium sulfate will usually be present as gypsum.

Because the differences in the crystalline morphology of hemihydrate and dihydrate solids not only reflect the chemical composition but also can affect the physical and engineering properties, it is convenient to classify FGC wastes on the basis of the ratio of calcium sulfate to total calcium-sulfur salts. The three categories are as follows:

- Sulfate rich ($CaSO_4/CaSO_x \geq 0.90$),
- Mixed ($0.25 < CaSO_4/CaSO_x < 0.90$), and
- Sulfite rich ($CaSO_4/CaSO_x \leq 0.25$),

where $CaSO_x$ is the total calcium-sulfur salts.

Calcium sulfite wastes present a problem because of the difficulty of dewatering. The slurry can be dewatered only to about 50-60% solids, producing an unstable, thixotropic material. However, calcium sulfite wastes can be oxidized to calcium sulfate, either intentionally in the scrubber or in an external oxidation reactor. From the viewpoint of utilization, calcium sulfate is the desirable FGD byproduct.

EPA studies at the Industrial Environmental Research Laboratory (Research Triangle Park, North Carolina) have shown that calcium sulfite can be readily oxidized to gypsum by simple air/slurry contact in the hold tank of the scrubber recirculation loop. Although the rate of oxidation reaches a maximum at a pH of 4.5 and then declines at higher pH, it was found that oxidation could be accomplished at a practical rate up to a pH of about 6.0 [38].

In Japan, where natural gypsum is not available, forced oxidation in scrubber systems has been employed extensively to produce a high-quality gypsum raw material for the cement and wallboard industries. In the United States, scrubber gypsum may be unable to compete extensively with the widely available natural gypsum. Thus, the incentive in the United States has been to develop simplified forced oxidation procedures directed only toward improving waste solids handling and disposal properties. As a disposal material, the gypsum waste can have high fly ash content; moreover, the oxidation reaction need be carried only to about 95% completion.

There is little information currently available on the composition of wastes from dry scrubbing systems utilizing spray dryers. However, while all of these would contain fly ash, the fraction of the waste resulting from SO_2 control would be expected to be similar in chemical composition to those produced by wet processes using the same sorbents. For lime-based dry scrubbing, the FGD wastes should consist primarily of a mixture of calcium sulfite, sulfate, and unreacted lime. The quantity of unreacted lime, however, may be somewhat higher than in wet scrubbing wastes owing to the higher stoichiometries that would probably be required. The mix of calcium sulfate and sulfite solids may also be somewhat different, both in terms of their relative quantities as well as the crystalline forms present.

For dry systems utilizing alkaline sodium salts (e.g., nahcolite or sodium bicarbonate) the waste solids would be expected to contain in addition to fly ash a mixture principally of sodium sulfate, sulfite, chloride, and unreacted carbonate. These would be similar, then, in composition to the wastes produced from once-through sodium solution scrubbing except that the solids would be discharged as a dry material rather than as a liquid.

Liquid Wastes

There are two different liquid waste-producing FGD processes that are in commercial operation on combustion boilers--(1) once-through scrubbing using solutions of alkaline sodium salts, and (2) scrubbing with ammonia-laden water. Of the two, once-through sodium scrubbing has achieved the widest acceptance, having been applied to many industrial steam plants and a few utility boilers. Once-through sodium scrubbing produces a waste liquor containing primarily sodium sulfate, sulfite, and chloride at total dissolved solids concentrations generally in the range of 15-30 wt%. Most of these waste liquors also contain significant particulate levels since the systems are used for combined particulate and SO_2 control. Frequently, the waste liquors are air-sparged to oxidize any residual sulfite to sulfate, especially where wastes are discharged for disposal.

2.1.2 Matrix of Disposal Options

Numerous methods are potentially available for the disposal of FGC wastes, the ultimate recipient being land or the ocean. The feasibility of disposal options can be categorized broadly on the basis of the nature of the wastes and the manner (type) of disposal.

Table 2.1 lists potential disposal options for the various types of FGC wastes which can be generated. An indication is given as to which options are being practiced on a commercial scale and which remain as reasonable potential. Sulfur is included in this table since long-term storage or even disposal of sulfur may be necessary in some applications of recovery systems. However, it is unlikely that many sulfur producing recovery processes would be installed without well-defined plans for sulfur utilization or marketing.

2.1.3 Current Disposal Practices

2.1.3.1 Current Fly Ash Disposal Practices

Disposal of fly ash or bottom ash is currently practiced at some 390 plants in the United States where coal is utilized at least as a part of the boiler fuel [6]. A complete survey of disposal practices is not available, although some general indications are available in FPC Form 67 data [6]. Such data, though, are sketchy and do not include handling information.

Radian [7], in a recent study, undertook a survey of 64 plants with a total capacity of 50,900 MW to develop some baseline information on ash disposal practices. Most of the plants contacted began operation

Table 2.1

Potential Disposal Options

	Ash	FGD Waste	Codisposal	Sulfur
Land Disposal				
Wet Pond - Conventional	C	C	C	-
Stacking (Gypsum)	-	P	P	-
Dry Impoundment	C	C	C	P
Surface Mine	C	P	C	P
Underground Mine	P	P	P	P
Ocean Disposal				
Shallow - Outfall	P	P	P	-
Concentrated (conventional) Dump	P	P	P	-
Dispersed Dump	P	P	P	-
Reef Construction (Stabilized)	P	-	P	-
Deep - Concentrated (conventional) Dump	P	P	P	-
Dispersed Dump	P	P	P	-

C - commercial practice

P - reasonable potential

in 1970-1978 and hence were relatively new. The data were characterized according to the disposal method used for each type of solid waste, the total coal-fired generating capacity of the plant, the solid wastes collection equipment and the type of FGD systems used. The data obtained are summarized in Tables 2.2 and 2.3. Provided the survey sampling is statistically representative of the industry (or, at least, the newer fraction of total capacity), it appears that:

- While a greater number of plants use ponding of fly ash, the greatest quantity of material is disposed by landfill. Radian reports that, of the 45 plants providing detailed information (representing about 36,000 MW), none sold their fly ash, but some of the paid disposal includes material that was eventually sold.
- The majority of plants use ESP to collect dry fly ash but dispose of the ash by ponding; only 30% of the plants have dry fly ash handling and disposal.
- Nearly 17% of the plants pay another company to dispose of or otherwise haul away the ash and 5% sell the ash directly to some company. In addition, a significant amount of the fly ash removed by paid disposal may be sold and utilized. Thus, the total amount of ash utilized is difficult to determine from the disposal data.

Considering the emergence of bag filters for fly ash collection and regulatory developments, the disposal of fly ash in managed fills in a relatively dry state (with water for fugitive emissions control only) is likely to be a major option.

2.1.3.2 Current Bottom Ash Disposal

The above-mentioned Radian survey [7] also included data on bottom ash disposal which is summarized in Tables 2.4 and 2.5. Providing the data are statistically representative of the industry, it appears that:

- On a plant basis, the vast majority wet sluice bottom ash but less than half of these plants use ponding for disposal. It is not known why this discrepancy exists.

Table 2.2

Fly Ash Collection and Disposal Practices

Basis: Radian Corporation Survey in 1978 for EPA

Method	Number of Plants Reporting Method	Percent of Plants Reporting Method
I. Collection		
Dry Electrostatic Precipitator	39	61
Mechanical (Baghouse, etc.)	8	13
Wet Electrostatic Precipitator	4	6
Particulate Scrubber	2	3
Other	11	17
Total	64	100
II. Disposal		
Ash Pond	26	40
Conveyed to Landfill (Dry)	19	30
Paid Disposal	11	17
Sale of Fly Ash	3	5
Intermediate Ponding followed by Landfill	3	5
Other	2	3
Total	64	100

Source: [7]

Table 2.3

Fly Ash Disposal Practices by Quantity of Ash

Basis: Radian Corporation Survey in 1978 for EPA

Disposal Method		Amount (10^3 metric tons/yr)	Percent of Total
Ponded		3,148	34
Landfill		4,763	51
Paid Disposal		1,415	15
Sold		--	--
Other		3	--
	Total	9,329	100

Source: [7]

Table 2.4

Bottom Ash Collection and Disposal Practices

Basis: Radian Corporation Survey in 1978 for EPA

Method	Number of Plants Reporting Method	Percent of Plants Reporting Method
I. Collection		
Wet Sluiced	52	81
Dry Conveyor	11	17
Other	1	2
Total	64	100
II. Disposal		
Ash Pond	24	38
Conveyed to Landfill (Dry)	17	27
Paid Disposal	8	12
Sale of Bottom Ash	6	9
Intermediate Ponding Followed by Landfill	6	9
Other	3	5
Total	64	100

Source: [7]

Table 2.5

Bottom Ash Disposal Practices by Quantity of Ash

Basis: Radian Corporation Survey in 1978 for EPA

Disposal Method	Amount (10^3 metric tons/yr)	Percent of Total
Ponded	1,763	44
Landfill	1,138	29
Paid Disposal	671	16
Sold	444	11
Total	4,016	100

Source: [7]

Mechanical dewatering and dry disposal of bottom ash do not appear to be common practice.

- On a quantity basis, the most common disposal method is ponding.

However, it is well to note that regulatory developments and economics may tend to encourage disposal of dewatered wastes in managed fills in the future.

2.1.3.3 Current FGD Waste Disposal

As of the end of 1978, nonrecovery FGD systems were in operation at 28 power stations and more than 40 industrial steam plants throughout the United States. Another eleven wet particulate scrubbing systems were also in operation at utility power plants. Although SO_2 control was not the primary function of these latter systems, they did achieve some degree of SO_2 removal, producing a waste containing a significant fraction of SO_2-related wastes. Including wet particulate scrubbing on utility boilers, the total FGD capacity amounted to an equivalent of about 21,000 MW.

Tables 2.6 and 2.7 summarize the operational FGD systems on utility and industrial applications at the end of 1978. The data shown in these tables were obtained from PEDCo reports [4, 5] and utility and industrial plant contacts.

Of the operational utility FGD systems listed in Table 2.6, all but that at Nevada Power Company's Reid Gardner Station produce a solid waste of calcium-sulfur salts. In contrast, the overwhelming majority of FGD systems on industrial boilers convert the SO_2 removed to a liquid waste of soluble sodium salts. Thus, while there are no definitive data on waste generation rates, it is clearly evident that most of the wastes being produced are solid wastes, and that essentially all of it is being generated by utility FGD systems. This is a trend which is expected to continue at least over the next ten years.

In order to gain a better perspective of waste generation and disposal in utility FGD systems, the information provided in Table 2.6 has been compiled in Table 2.8 according to waste type, disposal mode and general plant location. This compilation points out some interesting trends in current utility waste generation and disposal practices.

Table 2.6

Nonrecovery FGC Systems in Commercial Operation on Utility Boilers[a]

Utility	Plant	Capacity	Coal Sulfur Content (%)	Scrubbing System		Waste Form		Final Disposal
				Mode	Alkali	Source	Processing	
SO_2 CONTROL SYSTEMS:								
Alabama Electric Coop	Tombigbee (Unit 2)	225	0.8-1.5	SO_2	Limestone	Thickener	None	Wet Pond (L)
Arizona Electric Power Coop	Apache (Unit 2)	200	0.5-1.0	SO_2	Limestone	Scrubber	None	Wet Pond (u)
Arizona Public Service	Cholla (Units 1&2)	365	0.5	SO_2 + Ash	Limestone	Scrubber	None	Wet Pond (u)
Central Illinois Light	Duck Creek (Unit 1)	400	2.5-3.0	SO_2	Limestone	Thickener	Ash Added	Wet Pond (u)
City Utilities of Springfield	Southwest (Unit 1)	200	3.5	SO_2	Limestone	Filter	Nonproprietary Stab. (Ash + Lime)	Dry Fill
Columbus & Southern Ohio	Conesville (Units 5&6)	800	4.5-5	SO_2	Lime (Thiosorbic)	Filter	Commercial Stab. (IUCS)	Dry Fill
Duquesne Light	Elrama (Units 1-4)	510	2.0	SO_2 + Ash	Lime (Thiosorbic)	Filter	Commercial Stab. (IUCS)	Dry Fill
	Phillips (Units 1-6)	410	2.0	SO_2 + Ash	Lime (Thiosorbic)	Filter	Commercial Stab. (IUCS)	Dry Fill
Indianapolis Power & Light	Petersburg (Unit 3)	530	3-3.5	SO_2	Limestone	Filter	Commercial Stab. (IUCS)	Dry Fill
Kansas City Power & Light	Hawthorne (Units 3&4)	240	0.5-3	SO_2 + Ash	Lime	Thickener	None	Wet Pond (u)
	LaCyne (Unit 1)	820	5.0	SO_2 + Ash	Limestone	Scrubber	None	Wet Pond (u)
Kansas Power & Light	Jefferey (Unit 1)	620	0.5	SO_2	Limestone	Scrubber	Ash Added	Wet Pond (L)
	Lawrence (Units 4&5)	525	0.5	SO_2 + Ash	Limestone	Thickener	None	Wet Pond (u)
Kentucky Utilities	Green River (Units 1-3)	65	4.0	SO_2 + Ash	Lime	Scrubber	None	Wet Pond (u)
Louisville Gas & Electric	Cane Run (Units 4&5)	360	3.5-4.0	SO_2	Lime (Carbide)	Thickener	None	Wet Pond (u)[b]
	Mill Creek (Unit 3)	425	3.5-4.0	SO_2	Lime (Carbide)	Thickener	None (Codisposal in Ash Pond)	Wet Pond (u)[b]
	Paddy's Run (Unit 6)	65	3.5-4.0	SO_2	Lime (Carbide)	Filter	None (Codisposal in Ash Pit)	Dry Fill
Minnkota Power	Milton R. Young (Unit 2)	450	0.7	SO_2	Ash (+ Lime)	Filter	None	Dry Fill (Mine)
Montana Power	Colstrip (Units 1&2)	720	0.8	SO_2 + Ash	Ash (+ Lime)	Settling Pond	None	Wet Pond (u)
Northern States Power	Sherburne (Units 1&2)	1420	0.8	SO_2 + Ash	Limestone	Thickener	(Forced Oxidation)	Wet Pond (L)
Pennsylvania Power	Bruce Mansfield (Units 1&2)	1650	4.0-5.0	SO_2 + Ash	Lime (Thiosorbic)	Thickener	Commercial Stab. (Dravo)	Wet Pond (u)
Southern Carolina Public Service	Winyah (Unit 2)	140[c]	1.0	SO_2	Limestone	Thickener	None	Wet Pond (u)
Southern Mississippi Electric	R.D. Morrow (Unit 1)	180	1.0	SO_2	Limestone	Filter	None	Dry Fill
Tennessee Valley Authority	Widow's Creek (Unit 8)	550	3.0-4.0	SO_2	Limestone	Scrubber	Ash Added	Wet Pond (u)
Texas Utilities	Martin Lake (Units 1&2)	1585	1.0	SO_2	Limestone	Filter	Ash Added	Dry Fill (Mine)
	Monticello (Unit 3)	750	1.5	SO_2	Limestone	Scrubber	None (Codisposal in Ash Pond)	Wet Oibd (u)
Utah Power & Light	Huntington (Unit 1)	415	0.5	SO_2	Lime	Filter	Ash Added	Dry Fill
PARTICULATE CONTROL SYSTEMS - WET SCRUBBER:								
Arizona Public Services	Four Corners (Units 1-3)	575	0.8	Ash	(Lime)	Thickener/Settling Pond	None	Dry Fill (Mine)
Commonwealth Edison	Will County (Unit 1)	165	<1.0	Ash	(Limestone)	Thickener	Nonproprietary Stab. (Ash + Lime)	Dry Fill
Detroit Edison	St. Clair (Unit 6)	165	0.3	Ash	None	Scrubber	None	Wet Pond (L)
Minnesota Power & Light	Aurora (Units 1&2)	120	1.0	Ash	None	Scrubber	None	Wet Pond (u)
	Clay Boswell (Unit 3)	350	1.0	Ash	None	Thickener	None	Wet Pond (u)
Montana - Dakota Utilities	Louis & Clark (Unit 1)	50	0.7	Ash	(Limestone)	Scrubber	None	Wet Pond (L)
Nevada Power	Reid Gardner (Units 1-3)	375	0.5	Ash	(Soda Ash)	Scrubber	None	Wet Pond (u)
Pacific Power & Light	Dave Johnson (Unit 4)	330	0.5	Ash	(Lime)	Settling Pond	None	Dry Fill
Public Service Company of Colorado	Arapahoe (Unit 4)	100	0.6-1.0	Ash	None	Settling Pond	Lime Added	Dry Fill
	Cherokee (Units 1,3&4)	600	0.6	Ash	None	Thickener/Settling Pond	Lime Added	Dry Fill
	Valmont (Unit 5)	80[c]	0.7	Ash	None	Settling Pond	Limestone Added	Dry Fill
Southwest Public Services	Harrington (Unit 1)	350	0.5	Ash	(Limestone)	Thickener	None	Wet Pond (u)

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[a] Basis: November 1978

[b] Disposal operations will be converted in 1979 to dry impoundment with stabilization.

[c] One-half of boiler capacity is scrubbed

Source: Arthur D. Little, Inc.

Table 2.7

Nonrecovery FGD Systems in Commercial Operation on Utility Boilers[a]

Company	Plant	Flue Gas Handled (SCFM)	Fuel	Scrubber System		Waste Form	Waste Disposal[b]		
				Type	Mode		Dry Fill	Pond	Water Treated Discharge
SOLID WASTE:									
Armco Steel	Middletown, OH	84,000	LS Coal	Direct Lime	SO_2 + Ash	Slurry		X	
Caterpillar Tractor	East Peoria, IL	210,000	HS Coal	Dual Alkali	SO_2 + Ash	Filter Cake	X		
	Joliet, IL	67,000	HS Coal	Dual Alkali	SO_2 + Ash	Filter Cake	X		
	Morton, IL	40,000	HS Coal	Dual Alkali	SO_2 + Ash	Filter Cake	X		
	Mossville, IL	140,000	HS Coal	Dual Alkali	SO_2 + Ash	Filter Cake	X		
Firestone Tire & Rubber	Pottstown, PA	8,000	HS Coal	Dual Alkali	SO_2 + Ash	Filter Cake	X		
General Motors	Parma, OH	128,000	HS Coal	Dual Alkali	SO_2 + Ash	Filter Cake	X		
Rickenbacker Air Force Base	Columbus, OH	50,000	HS Coal	Direct Limestone	SO_2 + Ash	Thickened Slurry		X	
LIQUID WASTE:									
Alyeska Pipeline Service	Valdez, AK	50,000	LS Oil	Sodium Hydroxide	SO_2 (+ Ash)	Slurry			X
American Thread	Marion, NC	18,000	LS Coal	Waste Caustic	SO_2 + Ash	Slurry		X	
Beldridge Oil	McKittrick, CA	12,000	MS Oil	Sodium Hydroxide	SO_2	Solution			X
	McKittrick, CA	12,000	MS Oil	Sodium Hydroxide	SO_2	Solution			X
Canton Textiles	Canton, GA	25,000	LS Coal	Waste Caustic	SO_2 + Ash	Slurry		X	(X)
Chevron U.S.A.	Bakersfield, CA	248,000	MS Oil	Soda Ash	SO_2 (+ Ash)	Slurry		X	
FMC	Green River, WY	446,000	LS Coal	Soda Ash	SO_2	Solution		X	
General Motors	Dayton, OH	36,000	LS Coal	Sodium Hydroxide	SO_2 + Ash	Slurry			X
	Pontiac, MI	107,000	LS Coal	Sodium Hydroxide	Ash (+ SO_2)	Slurry	(X)		X
	St. Louis, MO	64,000	HS Coal	Sodium Hydroxide	SO_2	Solution			X
	Tonawanda, NY	92,000	LS Coal	Sodium Hydroxide	SO_2 + Ash	Slurry			X
Georgia Pacific	Crosset, AR	220,000	Bark/Oil/Coal	Waste Caustic	SO_2 + Ash	Slurry			X
Getty Oil	Bakersfield, CA	72,000	LS Coal	Soda Ash	SO_2	Solution		X	
Great Southern Paper	Cedar Springs, GA	420,000	Bark/Oil/Coal	Waste Caustic	SO_2 + Ash	Slurry		X	
Great Western Sugar	Billings, MT	60,000	LS Coal	Ammonia Water	SO_2	Solution			X
	Findlay, OH	65,000	LS Coal	Soda Ash	SO_2 + Ash	Slurry			X
	Fort Morgan, CO	65,000	LS Coal	Ammonia Water	SO_2 + Ash	Slurry		X	X
	Gering, NE	110,000	LS Coal	Ammonia Water	SO_2 + Ash	Slurry		X	X
	Greeley, CO	25,000	LS Coal	Ammonia Water	SO_2 + Ash	Slurry		X	X
	Loveland, CO	122,000	LS Coal	Ammonia Water	SO_2 + Ash	Slurry		X	X
	Scotts Bluff, NE	65,000	LS Coal	Ammonia Water	SO_2 + Ash	Slurry		X	X
ITT Rayonier	Fernandina Beach, FL	201,000	Bark/Oil	Sodium Hydroxide	SO_2 + Ash	Slurry		X	X
Kerr-McGee Chemical	Trona, CA	500,000	Coal/Coke/Oil	Caustic Brine	SO_2	Solution		X	X
Minn-Dak Farmer's Coop	Wahpeton, ND	105,000	LS Coal	Ammonia	SO_2 + Ash	Slurry			X
Mobil Oil	San Ardo, CA	182,000	HS Oil	Sodium Hydroxide	SO_2	Solution		X	
Sheller Globe	Norfolk, VA	8,000	LS Coal	Sodium Hydroxide	SO_2 + Ash	Slurry	X		X
St. Regis Paper	Cantonment, FL	115,000	Bark/Gas/Oil	Sodium Hydroxide	SO_2 + Ash	Slurry			X
Texaco	San Ardo, CA	366,000	MS Oil	Sodium Hydroxide	SO_2 + Ash	Slurry			X
Texas Gulf	Granger, WY	140,000	MS Oil	Soda Ash	SO_2	Solution			X

---

[a] Systems producing sulfur or where scrubber liquors are returned to process for use are not included.

[b] Notations for both wastewater treatment and ponding (or dry filling) indicate operations where solids are removed via settling (or filtration) and waste liquor is treated and discharge.

Source: Arthur D. Little, Inc.

Table 2.8

Summary of Disposal Practices for Operational FGC Systems on Utility Boilers as of November 1978

		Number of Plant/Plant Capacity								
		Western				Eastern				
			Wet Pond				Wet Pond			
Waste Form	System Type	Dry Fill	Lined	Unlined	Total	Dry Fill	Lined	Unlined	Total	TOTALS
FGD Waste Only	Lime-Based	--	--	--	0/0	--	--	--	0/0	0/0
	Limestone-Based	--	--	1/200	1/200	--	1/225	1/140	2/365	3/565
	Total	0/0	0/0	1/200	1/200	0/0	1/225	1/140	2/365	3/565
Codisposal	Lime-Based	2/865	--	2/960	4/1825	1/65	--	3/850	4/915	8/2740
	Limestone-Based	1/1585	2/2040	4/2460	7/6085	1/180	--	2/950	3/1130	10/7215
	Wet Particulate Scrubbing	5/1685	1/50	4/1195	10/2930	--	1/165	--	1/165	11/3095
	Total	8/4135	3/2090	10/4615	21/10840	2/245	1/165	5/1800	8/2210	29/13050
Stabilized FGD Waste	Lime-Based	--	--	--	0/0	3/1720	--	1/1650	4/3370	4/3370
	Limestone-Based	--	--	--	0/0	2/730	--	--	2/730	2/730
	Wet Particulate Scrubbing	--	--	--	0/0	1/165	--	--	1/165	1/165
	Total	0/0	0/0	0/0	0/0	6/2615	0/0	1/1650	7/4265	7/4265
TOTALS		8/4135	3/2090	11/4815	22/11040	8/2860	2/390	7/3590	17/6840	39/17880

Source: Arthur D. Little, Inc.

- Of the total number of FGD plant installations and FGD plant capacity, 60% (23 plants and about 10,900 MW) utilize wet ponding for ultimate disposal while 40% (16 plants and about 7,000 MW) use some form of dry fill.
- Of the FGD systems utilizing ponding, approximately three-quarters involve unlined ponds, and only about one-quarter involve lined ponds. (The majority of systems also prethicken wastes prior to pumping to the disposal ponds.)
- Of those systems utilizing dry fill, the overwhelming majority of plants (about 80%) operate dry landfill-type impoundments, although three plants (20%) are currently disposing of wastes in surface mines.
- Over 90% of the plants and FGD capacity utilize codisposal (with or without stabilization).
- There are no operating utility systems involving dry fill of ash-free FGD wastes (nor is there any industrial-scale dry fill of ash-free wastes).
- There is no stabilization of FGD wastes in Western plants.

While about 40% of the utility FGD systems currently utilize some form of dry impoundment, the trend toward dry impoundment is expected to grow over the near future. In 1979, an additional 7,500 MW of nonrecovery FGD capacity is due to come on line, all of which will involve SO_2 control only. Of this total, 6,700 MW will produce solid wastes, approximately 85% of which involve some form of dry impoundment. Thus, by the end of 1979, the capacity of nonrecovery FGD systems involving dry impoundment will grow to 50% of the total utility FGD capacity.

2.1.4 Field Studies of FGC Waste Disposal

There are now underway eight field-scale test and monitoring programs of FGC waste disposal. Five more programs are in planning and are scheduled to begin sometime in 1979, and another is being proposed.

Table 2.9 lists these field testing programs along with the sponsors, contractors and the range of waste and disposal modes tested.

It is interesting to note that these programs encompass all types of FGD wastes as well as all of the basic disposal modes available. Of particular importance are the full-scale and prototype studies. Most of these focus on one type of waste or disposal mode.

An upcoming program of significance is the multiple-site test program planned by EPA. It will involve monitoring more than a dozen FGC waste disposal sites including a variety of different types of wastes and disposal modes. This two-year effort is scheduled to begin in late 1979.

The scope of each of the programs listed in Table 2.9 is discussed briefly below. These studies will be referenced and highlighted throughout the remainder of this report as they apply to specific issues.

Basis: Status as of November 1978

Location Utility (Plant)*	Sponsor(s)*	Principal Contractor(s)*	Scrubber System		Waste Characteristics		Disposal Mode	Test Area	Program Status
			Mode	Type	Type	Form			
LAND DISPOSAL:									
Minnkota Power (M.R. Young)	EPA	UND/ADL	SO_2 Only	Alkaline Ash	Sulfate-Rich	Filter Cake (Unstabilized)	Surface Mine	Section of Mine	Underway
Gulf Power (Scholz)	EPRI	CIC/Radian	SO_2 Only	Limestone	Gypsum	Thickened Slurry (Unstabilized)	Trenching	~1-acre Area	Underway
Gulf Power (Scholz)	EPA/EPRI	CEA/ADL	SO_2 Only	Dual Alkali	Sulfite-Rich	Filter Cake (Stabilized & Unstabilized)	Dry Impoundment	1-acre Pit	Planning
Columbus & S. Ohio (Conesville)	EPRI	MBA/[illegible]	SO_2 Only	Lime (Thiosorbic)	Sulfite-Rich	Filter Cake (Stabilized)	Dry Impoundment	10-acre Site	Planning
Louisville Gas & Electric (Paddy's Run)	EPA	CE/LGE/UL	SO_2 Only	Lime (Carbide)	Sulfite-Rich	Filter Cake (Stabilized & Unstabilized)	Dry Impoundment	Small Pits/Ponds	Underway
Louisville Gas & Electric (Cane Run)	EPA	Bechtel	SO_2 Only	Dual Alkali	Sulfite-Rich	Filter Cake (Stabilized)	Dry Impoundment	?	Planning
TVA (Shawnee)	EPA/TVA	TVA/Bechtel /Aerospace	SO_2 & SO_2 + Ash	Lime & Limestone	Sulfite-Rich	Filter Cake Centrifuge Cake Thickened Slurry (Stabilized & Unstabilized)	Wet & Dry Impoundments	6 Pits (<.1 acre)	Underway
			SO_2 Only	Limestone (Forced Oxidation)	Gypsum	Filter Cake	Dry Impoundment	4 Pits/Acres	Underway
OTHER DISPOSAL:									
Duquesne (Elrama/Phillips)	DOE/EPA/EPRI/NYSERDA/PASNY	SUNY/IUCS	SO_2 + Ash	Lime (Thiosorbic)	Sulfite-Rich	Filter Cake (Stabilized)	Reef Construction	~0.2 Acre	Underway
Many —	EPA	NEA/ADL	SO_2 & SO_2 + Ash	Many	Many	Many	Concentrated Dump	1/2-acre Pond	Underway

---

*ADL - Arthur D. Little
CE - Combustion Engineering
CEA - Combustion Equipment Associates
CIC - Chiyoda International
DOE - Department of Energy
EPA - U.S. Environmental Protection Agency
EPRI - Electric Power Research Institute
IUCS - IU Conversion Systems
LGE - Louisville Gas and Electric
MBA - Michael Baker Associates
NEA - New England Aquarium
NYSERDA - New York State Energy Research & Development Authority
PASNY - Power Authority of the State of New York
SUNY - State University of New York
TVA - Tennessee Valley Authority
UL - University of Louisville
UND - University of North Dakota

Table 2.9

Summary of Current Field Testing Programs for FGC Waste Disposal

Basis: Status as of November 1978

Location Utility (Plant)[a]	Sponsor(s)[a]	Principal Contractor(s)[a]	Scrubber System Mode	Scrubber System Type	Waste Characteristics Type	Waste Characteristics Form	Disposal Mode	Test Area	Program Status
LAND DISPOSAL:									
Minnkota Power (M.R. Young)	EPA	UND/ADL	SO_2 Only	Alkaline Ash	Sulfate-Rich	Filter Cake (Unstabilized)	Surface Mine Stacking	Section of Mine ~1-Acre Area	Underway Underway
Gulf Power (Scholz)	EPRI	CIC/Radian	SO_2 Only	Limestone	Gypsum	Thickened Slurry (Unstabilized)	Dry Impoundment	1-Acre Pit	Planning
Gulf Power (Scholz)	EPA/EPRI	CEA/ADL	SO_2 Only	Dual Alkali	Sulfite-Rich	Filter Cake (Stabilized & Unstabilized)	Dry Impoundment	30-Acre Site	Planning
Columbus & S. Ohio (Conesville)	[illegible]	MBA/Battelle	SO_2 Only	Lime (Thiosorbic)	Sulfite-Rich	Filter Cake (Stabilized)	Dry Impoundment	Small Pits/Ponds	Underway
Louisville Gas & Electric (Paddy's Run)	EPA	CE/LGE/UL	SO_2 Only	Lime (Carbide)	Sulfite-Rich	Filter Cake (Stabilized & Unstabilized)	Dry Impoundment	?	Planning
Louisville Gas & Electric (Cane Run)	EPA	Bechtel	SO_2 Only	Dual Alkali	Sulfite-Rich	Filter Cake (Stabilized)	Wet & Dry Impoundments	6 Pits (<.1 Acre)	Underway
TVA (Shawnee)	EPA/TVA	TVA/Bechtel /Aerospace	SO_2 & SO_2 + Ash SO_2 Only	Lime & Limestone Limestone (Forced Oxidation)	Sulfite-Rich Gypsum	{Filter Cake / Centrifuge Cake / Thickened Slurry} (Stabilized & Unstabilized) Filter Cake	Dry Impoundment	4 Pits/Areas	Underway
OCEAN DISPOSAL:									
Duquesne (Elrama/ Phillips)	DOE/EPA/EPRI/ NYSERDA/PASNY	SUNY/IUCS	SO_2 + Ash	Lime (Thiosorbic)	Sulfite-Rich	Filter Cake (Stabilized)	Reef Construction	~0.2 Acre	Underway
Many ---	EPA	NEA/ADL	SO_2 & SO_2 + Ash	Many	Many	Many	Concentrated Dump	1/2-Acre Pond	Underway

---

[a] ADL - Arthur D. Little
CE - Combustion Engineering
CEA - Combustion Equipment Associates
CIC - Chiyoda International
DOE - Department of Energy
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MBA - Michael Baker Associates
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PASNY - Power Authority of the State of New York
SUNY - State University of New York
TVA - Tennessee Valley Authority
UL - University of Louisville
UND - University of North Dakota

2.2 Disposal on Land

At present, all FGC wastes are disposed of on land. There are five basic modes of land disposal, as noted in Table 2.1, which are considered as potential options for large-scale disposal operations:

a. Wet ponding

- Conventional wet ponding of coal ash, FGD wastes and stabilized FGD wastes as now commonly practiced.
- Gypsum stacking which is not now practiced but which is being investigated for FGD gypsum.

b. Impoundment of dry or dewatered wastes in managed fills including: direct impoundment of ash, FGD wastes, combined ash and FGD wastes (codisposal), and stabilized wastes; and excavation and landfilling of wastes from interim ponds.

c. Mine disposal

- Surface mine disposal including pit bottom and spoil bank placement of wastes.
- Underground mine disposal.

Of these five basic options, only three are now being commercially practiced. There are no stacking or underground mine disposal operations at present. However, all of these are expected to be practiced in some form or other in the near future. Table 2.10 summarizes the five modes and principal variations in terms of commercial practice.

2.2.1 Wet Ponding

2.2.1.1 Conventional Practice

Wet ponding is presently more widely employed than any other method but is expected to be less widely used in the future. A number of engineering variations are possible in a ponding system. To provide a background on some pond operations, a brief summary of five ponding operations is presented in Table 2.11. Schematic diagrams of each of the five ponding schemes are presented in Figures 2.1 to 2.5.

The implementation of a pond disposal system depends upon the type of wastes being generated and the manner in which it is handled. In the case of dry fly ash collection systems, the ash can be either directly sluiced using a hydrovac system and pumped to the pond, or pneumatically conveyed to a transfer system where the ash is mixed with sluice water and pumped to the pond. Bottom ash is usually removed from the bottom

Table 2-10

Summary of Land Disposal of FGC Wastes

		Variation	Type of Waste[a]			
			Ash	FGD Only	Codisposal	Stabilized FGC
Wet Ponding						
	Conventional	Lined	X	X	X	
		Unlined	X	X	X	X
	Stacking	--				
Dry Impoundment		—	X		X	X
Mine Disposal						
	Surface	Pit Bottom	X		X	
		Spoil Bank	X		X	
	Underground	Wet Waste				
		Dry Waste				

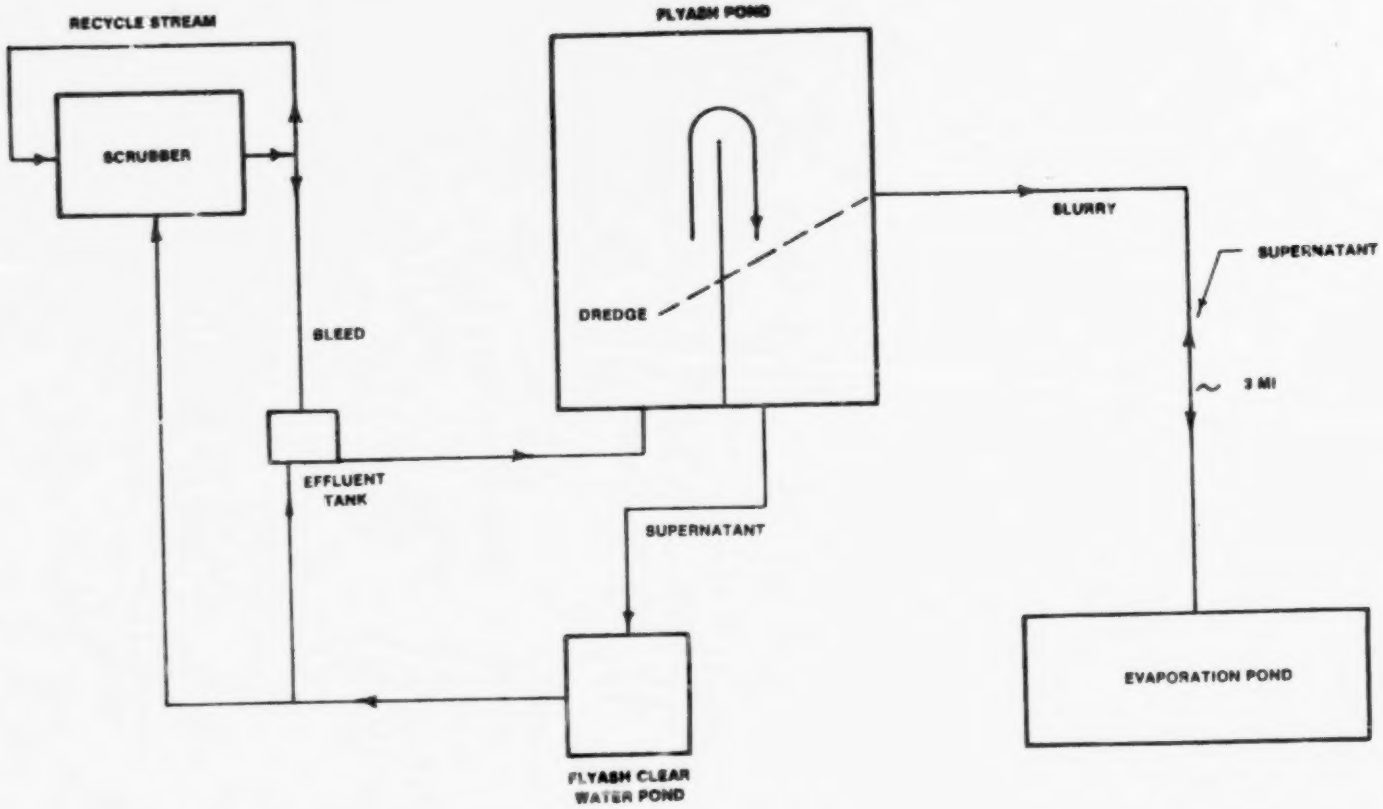
[a] X - Indicates being commercially practiced.

Table 2.11

Typical FGD Waste Disposal Operations - Wet Disposal

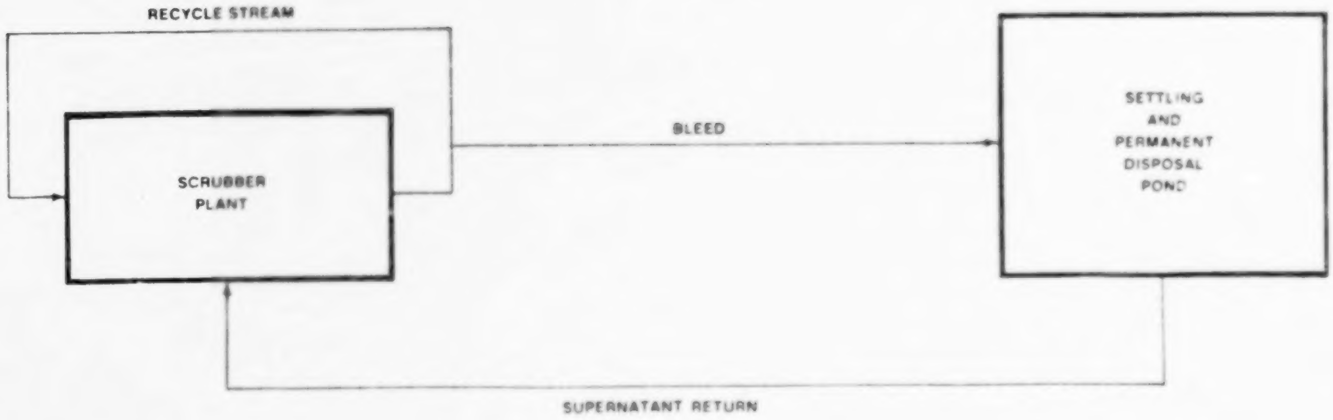
No.	Detail	Colstrip Plant	LaCygne Plant	St.Clair Plant	Sherburne Plant	Bruce Mansfield Plant
1	Company and Location	Montana Power, Colstrip, Montana	Kansas City Power & Light Linn County, Kansas	Detroit Edison Belle River, Michigan	Northern State Power Becker, Minnesota	Pennsylvania Power Shipping Port, Penn.
2.	Plant Size MW	716	874	325	1500	1620
3.	Fuel (average values)	Ash=8.6%; S=0.77%	Ash=24-25%; S=5.6%	Ash=4.25%; S-0.75%	Ash=9%; S=0.8%	Ash=12.5%; S=4.3%
4.	FGC System	'ZA Venturi Scrubber & Koch Tray + Absorber Tray.	B&W Venturi + 2-stage Perforated Tray Absorber	Peabody-Lurgi Venturi Scrubber	CE Venturi + Marble Bed Scrubber	Chemico Scrubber & Absorber System
5.	Scrubber Reagent	Alkaline Fly Ash and Lime.	Limestone	Limestone	Alakaline Fly Ash and Limestone.	Lime
6.	Waste Disposal	Settling Pond + Evaporation Pond	Ponding	Clay-lined Pond	Thickening and Permanent Disposal Pond	Dravo Process Stabilization and Permanent Disposal Pond
7.	Reference	[5,9]	[10]	[11]	[5,9]	[12,13]

2.26


RECYCLE STREAM
SCRUBBER
FLYASH POND
DREDGE
SLURRY
SUPERNATANT
~ 3 MI
BLEED
EFFLUENT TANK
SUPERNATANT
FLYASH CLEAR WATER POND
EVAPORATION POND

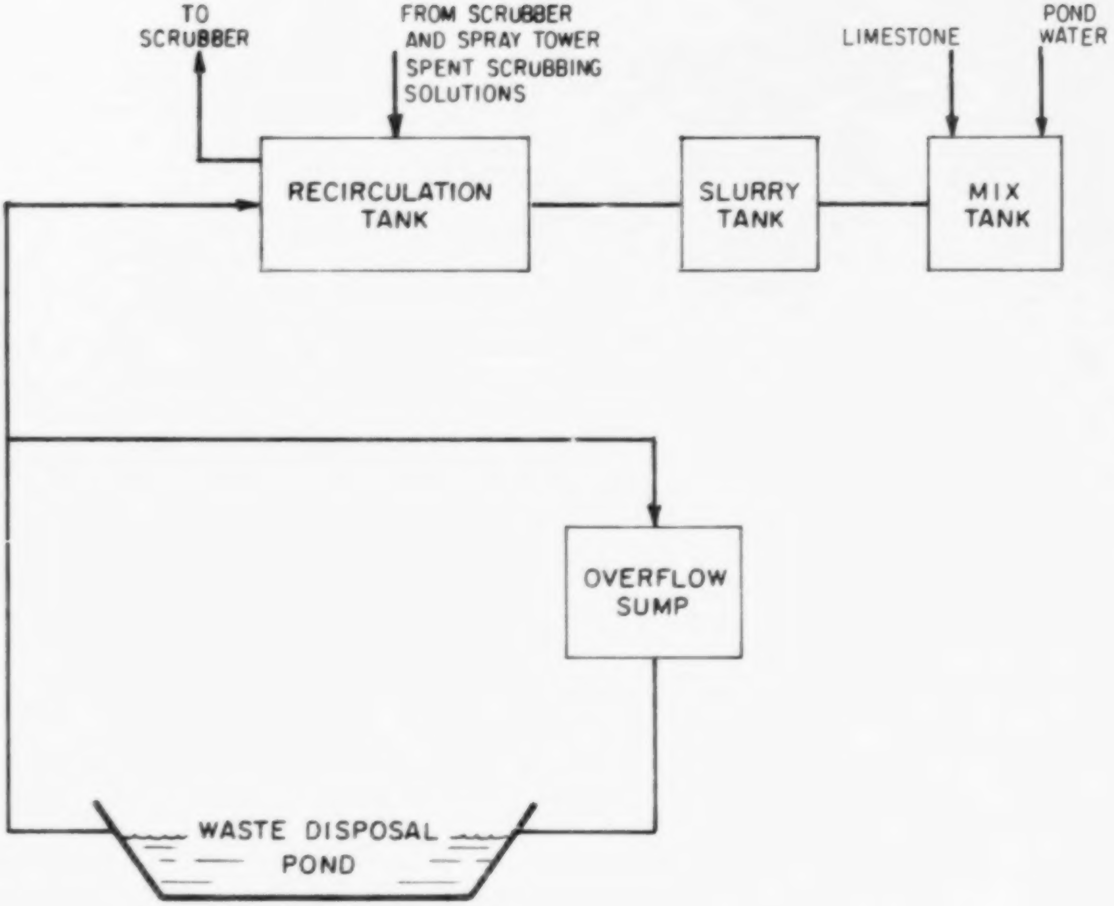
Source: [9]

Figure 2.1 Waste Handling Colstrip Plant
Montana Power Company


RECYCLE STREAM
SCRUBBER PLANT
BLEED
SETTLING AND PERMANENT DISPOSAL POND
SUPERNATANT RETURN

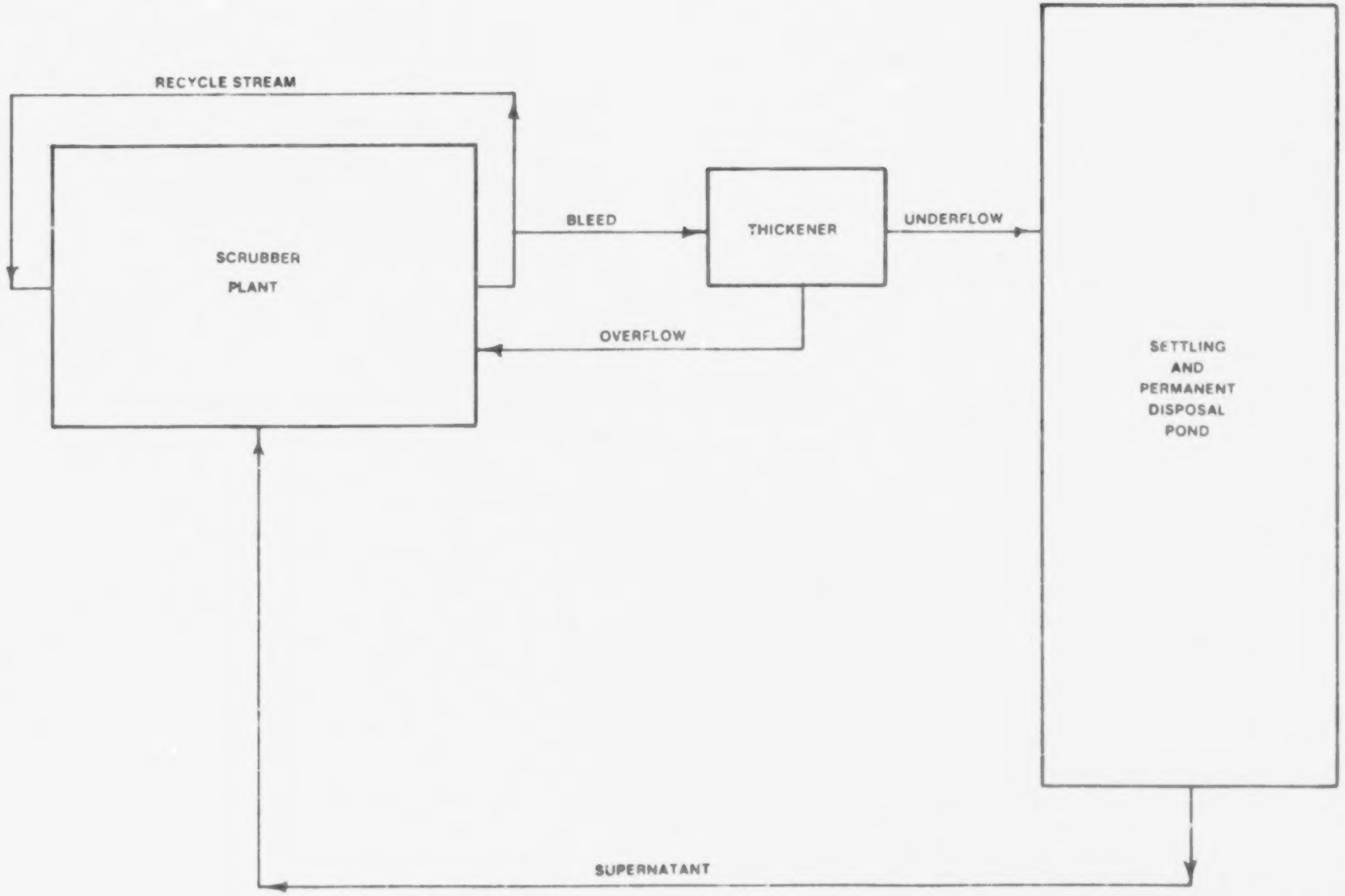
Source: [9]

Figure 2.2 Waste Handling LaCygne Station
Kansas City Power & LIght Company


TO SCRUBBER
FROM SCRUBBER AND SPRAY TOWER SPENT SCRUBBING SOLUTIONS
LIMESTONE
POND WATER
RECIRCULATION TANK
SLURRY TANK
MIX TANK
OVERFLOW SUMP
WASTE DISPOSAL POND

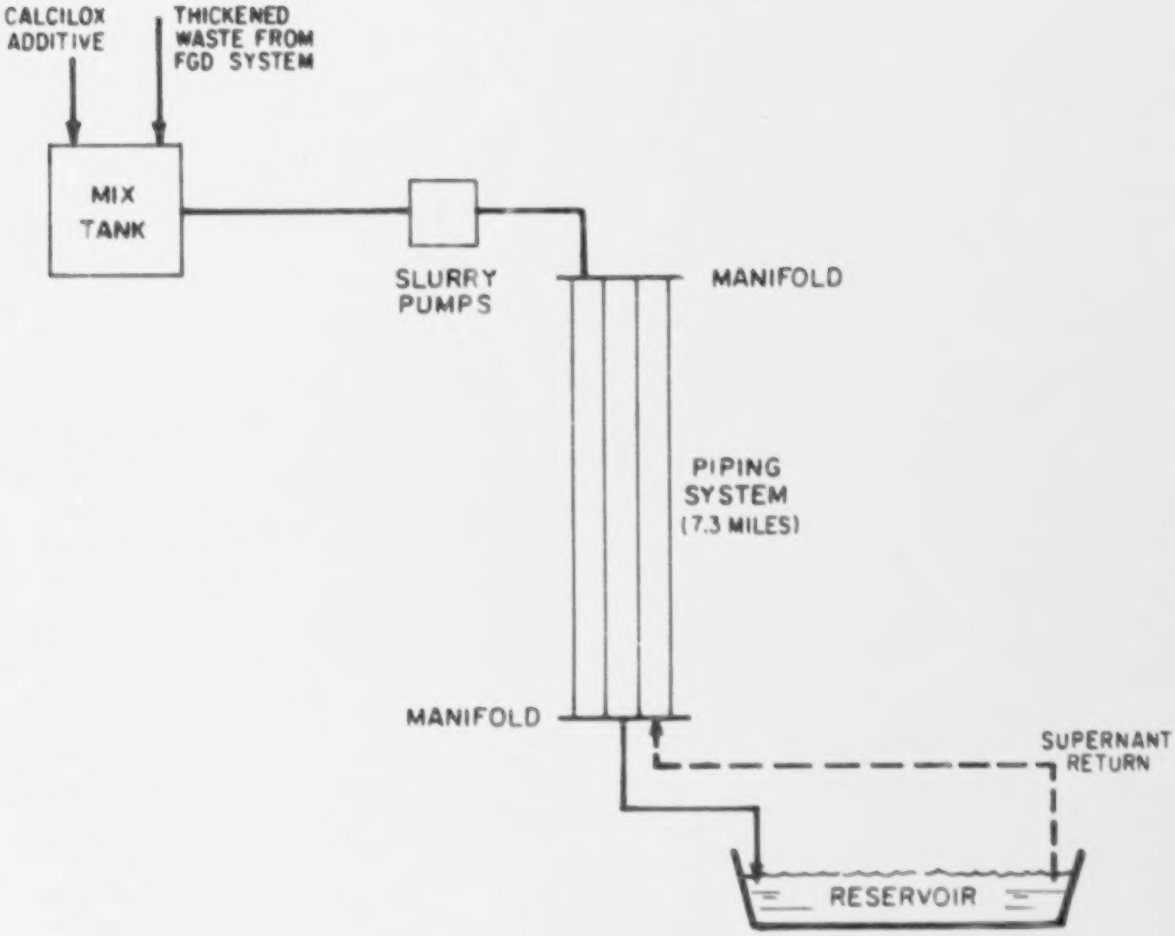
Source: [11]

Figure 2.3 Waste Handling St. Clair Plant - Detroit Edison Company


RECYCLE STREAM
SCRUBBER
PLANT
BLEED
THICKENER
UNDERFLOW
OVERFLOW
SETTLING
AND
PERMANENT
DISPOSAL
POND
SUPERNATANT

Source: [9]

Figure 2.4 Waste Handling Sherburne Plant - Northern States Power Company


CALCILOX ADDITIVE
THICKENED WASTE FROM FGD SYSTEM
MIX TANK
SLURRY PUMPS
MANIFOLD
PIPING SYSTEM (7.3 MILES)
MANIFOLD
SUPERNANT RETURN
RESERVOIR

Source: [12]

Figure 2.5 Waste Handling - Bruce Mansfield Plants - Pennsylvania Power Company

of the boiler using a sluicing system and pumped separately to a disposal pond (sometimes a separate pond from that used for fly ash). In the case of wet scrubbers, wastes from particulate control, SO_2 control, or combined particulate and SO_2 control systems, there are two basic approaches. The wastes can be pumped directly from the scrubber to the disposal pond, or the wastes can be dewatered first via thickening/clarification prior to being pumped to the pond. In some wet scrubber systems for SO_2 control, the wastes (thickened or unthickened) are first mixed with sluiced ash or combined with additives for stabilization.

In almost all cases, provision is made for returning supernate to the process. This is particularly true for ash ponding systems and FGD systems discharging unthickened wastes directly to ponds. Here, water management and conservation dictate water reuse. However, not all ponding systems incorporate water recycle and many which do include this feature practice only partial recycle. For new systems constructed in the future, recycle and optimum water management are anticipated to be mandatory.

Wet ponding may be technically employable for a variety of FGC wastes including stabilized FGD wastes only if two conditions are met:

- A site is available that can be converted into a reservoir with minimum construction of dams or dikes or excavations. Otherwise, costs rise rapidly.
- The additive for wet stabilization is available at reasonable cost. Lime-fly ash stabilization processes cannot be applied to slurries (only to dewatered FGC wastes). Dravo's process using Calcilox® additive is the only stabilization process commercially available for stabilizing slurried FGC wastes. Such specialized additives may be manufactured at one or few locations. Transportation costs for the additives beyond a certain distance from point of manufacture may be high and preclude such stabilization processes.

Nevertheless, under site specific conditions, these processes can be applied. In addition to Bruce Mansfield, Allegheny Power System's

Point Pleasant Plant will employ an analogous Dravo system. This is likely to be operational in 1979 [14].

An important consideration in pond design is control of leachate movement. The conventioanl approach is to site ponds in areas where the underlying soil has low permeability. Dams are constructed of borrow material of low permeability to minimize seepage. If the wastes were hazardous and were to be regulated under Section 3004 (which does not apply to FGC wastes), earthen dikes would be required to be formed of relatively impervious soil. If the permeability of the wastes and the underlying soils are not sufficiently low to control seepage to desired levels, artificial liners or sealants can be employed. This is not common practice for FGC waste disposal by ponding and may not be required for stabilized FGD wastes. Where needed, the potential options for liners are:

- Clay sealants like bentonite mixed with granular soils. They offer superior linings for landfills and ponds because they provide acceptably low permeabilities and can be expected to self-seal in the event of a rupture. Their main drawback, however, is a high transport cost when not available locally.
- Chemical sealants--These are sprayed into the soil in a landfill or pond in order to plug the interstices. They can be difficult to apply, but are less expensive than clay sealants in areas where swelling clays are unavailable. However, chemical sealant liners are more permeable than those of clay.
- Synthetic liners--Synthetic liners are the most effective type available. They can be effective and are easy to install but puctures can seriously nullify their effectiveness. Field experience with such liners in large ponds is limited.
- Stabilized FGD wastes, themselves, can be employed as liners.

Two important elements in a ponding system are:

- Design of the pond itself, and
- Design of the pipeline system including interfacing.

These are discussed below.

Pond Design

Pond design is based on construction of dams or dikes and, in a few cases, based on excavations in the ground. Ponds can be built on slopes. Some potential pond designs are illustrated in Figure 2.6. However, the construction of dikes or other means of containment for ponds is usually expensive. In the future, particularly if stabilization of FGD wastes is widely practiced, ponding will probably be limited to those sites that can be converted to a pond with minimal construction of dams or dikes.

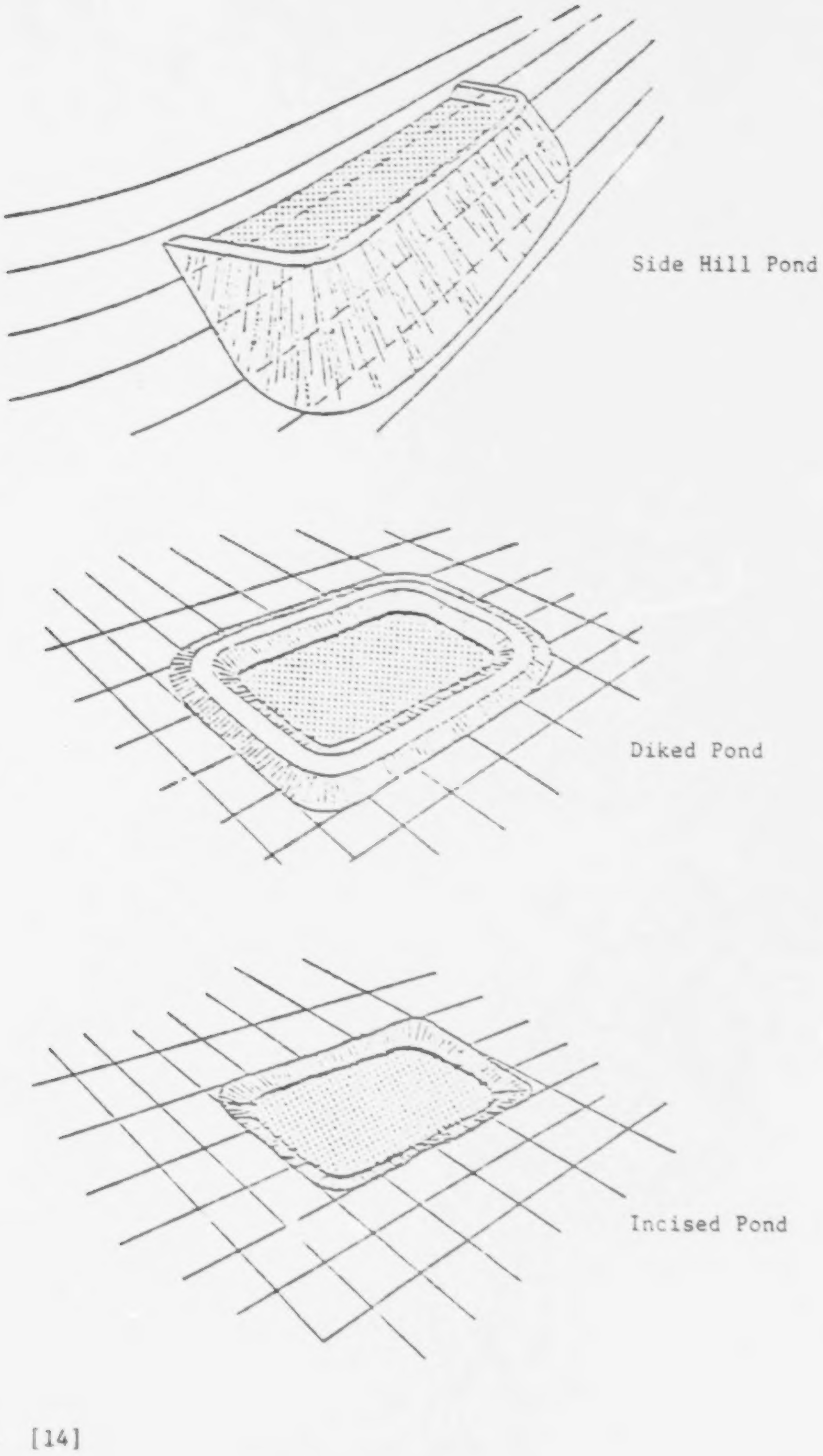
Pipeline Systems

The four principal factors most important to the design of pipeline systems are:

- Solids settling,
- Erosion/abrasion potential,
- Corrosion potential, and
- Freeze protection.

Of these, avoidance of solids settling in pipelines is usually the overriding factor in design. Usually, an FGC waste can be conveyed hydraulically. To prevent settling, conveying velocities usually range between 1.5 meters and 3.7 meters per second (5-12 ft/sec), depending on material density, particle size and conveyor pipe configuration [16]. For coarser materials, such as bottom ash and mill rejects, conveying velocities will be in the higher range, particularly in vertical pipes such as may be encountered when pumping to elevated dewatering bins. In long pipelines handling coarse materials, velocities must be increased above those used for shorter lines. In addition, some device to create turbulence must be introduced to maintain homogeneous slurry mix, particularly when conveying bottom ash or mill rejects. Fly ash slurries with finer particles can be pumped at the lower range of velocities as can be FGD wastes.

A key parameter in pipeline system design is the percentage of solids in the slurry. This is determined by the three fundamental


Side Hill Pond
Diked Pond
Incised Pond

Source: [14]

Figure 2.6 Pond Designs

physical properties: crystal morphology, particle size, and density of the waste. System design should emphasize reliability of service and avoidance of maintenance problems like settling, plugging or solids buildup in critical parts. FGD wastes and fly ash are often conveyed at 10% to 25% solids while higher loadings are possible for bottom ash. The bulk density of the conveyed slurry is usually well below 1.2 gm/cc.

It is also noted that pipeline optimization is only important if the line exceeds about 1,200 meters (4,000 feet) in length. The usual practice in short pipelines is to convey the waste as a dilute slurry and provide adequate redundancy to ensure reliability of service.

Radian [7] reports on distance to disposal site for 54 plants and concluded that:

- Nearly 93% of all bottom ash and fly ash from the representative 54 plants is transported less than 8 kilometers (five miles) from the generating plant to the ultimate disposal site. This is a strong indication that the cost of transporting large volume wastes over long distances is generally avoided.
- The mean distance from the plant to disposal sites was 4.8 kilometers (three miles) for this representative group of 54 plants and is considered realistic for the industry as a whole.

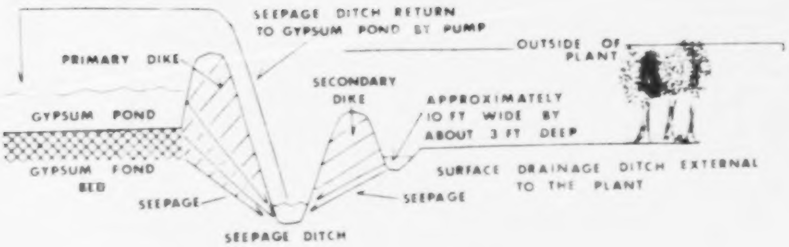
2.2.1.2 Gypsum Stacking

FGD processes can produce gypsum either by intentional forced oxidation or in cases when the sulfur content of the coal is low. In either case, the special case of wet ponding called "gypsum stacking" may be applicable even though it is not practiced now. EPRI is sponsoring a study of gypsum stacking at the Scholz plant of Gulf Power Company in conjunction with the testing of the prototype Chiyoda 121 FGD process.

It should be noted that gypsum stacking is common practice in the phos-acid industry. A brief description of gypsum stacking as it is practiced in the phos-acid industry [17] is given below to provide some insight on how it may be applied to FGD gypsum. However, data are not available to indicate that phos-gypsum and FGD gypsum are fully analogous in terms of physical and chemical characteristics. For example, occluded waste liquor in phos-gypsum is quite acidic (pH of 2 to 3). FGD gypsum liquor, on the other hand, has a significantly higher pH. This factor alone may cause differences in physical stability of the gypsum in the stacking operation.

The phos-gypsum waste is usually transported as a waste by pipeline to a pond created by construction of starter dams usually from local borrow materials. Phos-gypsum as a slurry is discharged by spigotting into the pond. Gypsum settles rapidly and supernate is piped back to the process plant and used as makeup water. As the quantity of gypsum builds up in the pond, the freeboard between pond level and dike top decreases. When the freeboard between pond level and dike top needs to be increased, the dike is raised by borrowing material from the dried surface of the previously deposited gypsum, and the cycle is repeated. Dredging and dozing are the usual means of achieving the buildup of the dike. The operation is usually conducted in such a way that deep trenches are not left along inside edges of embankments. With this method, each successive dike moves further upstream and is underlain by the previously deposited gypsum. In some cases, these dikes permit seepage of contaminated water through them. It is necessary to collect and reimpound seepage, primarily because of the fluoride present in it. Seepage collection and reimpoundment are facilitated by construction of a seepage collection ditch around the perimeter of the gypsum pond, as depicted in Figure 2.7, along with a pump station at the collection point of the seepage ditch to move the collected seepage water back into the gypsum pond [18]. Permeability of the dams or dikes can be minimized by segregation of phos-gypsum fines if needed [19]. Seepage collection may not be required for FGD gypsum except in site specific cases.

Preliminary indications from EPRI's test program on FGD gypsum stacking are favorable. Tests are continuing and are expected to be completed by late 1979 [15].


SEEPAGE DITCH RETURN TO GYPSUM POND BY PUMP
PRIMARY DIKE
OUTSIDE OF PLANT
SECONDARY DIKE
APPROXIMATELY 10 FT WIDE BY ABOUT 3 FT DEEP
GYPSUM POND
GYPSUM FOND BED
SURFACE DRAINAGE DITCH EXTERNAL TO THE PLANT
SEEPAGE
SEEPAGE
SEEPAGE DITCH

Source: [18]

Figure 2.7 Proposed Gypsum Pond Water Seepage Control System Using a Collection Ditch Around the Perimeter (EPA Effluent Guidelines Document)

2.2.1.3 Research Efforts in Ponding

Recent study efforts in this means of disposal have centered on two issues:

- Most effective means of containing pollutants within the disposal area; i.e., study of potential liner material, and
- Better definition of leaching from lined and unlined ponds.

Liners for Ponds

Unlined disposal ponds are usually the least expensive method of waste disposal. This technique, however, has been subject to criticism, primarily due to the potential for waste contaminants to enter the groundwater. Nonetheless, many FGD waste disposal systems in operation use unlined ponding for either intermediate clarifying or ultimate disposal. The use of unlined ponds for waste disposal is expected to decrease in the future.

Liners can be of any material including site soils (properly treated) or materials not native to the site and are used to reduce permeation. Liners potentially can reduce pollutant mobility and can conserve water for recycle. At present, the major problem with liners has been high cost and lack of real time experience under field conditions (i.e., questionable longevity).

In principle, the criteria that are important for a liner material are [20]:

- High strength and elasticity,
- Good weatherability and long life expectancy,
- Resistance to bacterial and fungal attack, and
- Ease of repair.

In addition, the pond design may include a leakage detection system. One such system consists of underbed drainage channels which collect the leakage in a visible sump for periodic observation. Other methods of visible detection include standpipes and wells. Techniques of measuring ground resistivity have been developed and may also be applicable.

No reliable data are available on the long-term effects of FGC wastes leachate on disposal site liner materials. The permeability of plastic liners is claimed to be zero but the durability of such liners in a disposal site for FGC wastes has not been demonstrated. Clay liners would have more strength, ductility and durability than synthetic liner materials because of inherent plasticity and buffering capacity, but clays possess finite permeability. Coefficients of permeability for clay soils usually range from 10^{-7} cm/sec to 10^{-9} cm/sec, for homogeneous unweathered masses of normally consolidated clay. Preloading (with formation of cracks), weathering or inclusion of coarser soil zones (silt lenses, for example) can produce higher permeabilities in clay masses. FGC wastes tend to be more permeable than clay soils, but the long-term permeability of fixed wastes may be as low as that of some clays. Tests on unfixed wastes have not been reliable in that sample preparation has not been appropriate in some studies, while in other studies inappropriate testing methods have been used. Permeability test results have varied from 10^{-3} cm/sec to 10^{-6} cm/sec or lower (10^{-6} cm/sec is slightly more than one foot per year). Reliable data on wastes permeability are needed.

At present, two important studies are ongoing and may yield useful results:

a. The U.S. Army Corps of Engineers Waterways Experiment Station (WES) is conducting a program to: (1) determine the compatibility of 18 liner materials with flue gas cleaning (FGC) wastes and associated liquors and leachates; (2) estimate the length of life for the liners; and (3) assess the economics involved with purchase and placement (including disposal area construction) of various liner materials. The liners that WES is testing include:

- Admixture types (cement, lime, fly ash),
- Prefabricated liner membranes (polymer, neoprene coated, etc.), and
- Spray-on types (polyvinyl acetate, latex, asphalt, cement, etc.).

Results of this investigation are likely to be available in 1979.

b. In 1978 EPRI initiated a program to evaluate leachate control and monitoring systems for solid waste disposal facilities. The objective is to evaluate liner materials for utility solid wastes. This 36-month program which will be underway in 1979 may yield substantial technical data on a number of liner materials.

Leaching from Ponds

The extent of leaching of pollutants from disposal ponds is dependent on several factors: the hydrostatic head in the pond, which forces percolation through the pond bottom; the nature of the waste--primarily the permeability and the solubility of contaminants it contains; and finally, the characteristics of the soil beneath the pond. At present, monitoring wells exist in some of the FGC waste disposal ponds including large ones like Bruce Mansfield. However, for the better designed systems, adequate time has not elapsed for meaningful data to be available at present. Efforts are continuing in this field, and additional insight on field site leaching is likely to be available in the future.

EPA recently announced [21] that a major project of characterization and environmental monitoring of full-scale utility disposal sites for regulation development will be undertaken. This effort will cover monitoring of about 16 sites to obtain background data and information to promulgate guidelines or regulations for management of FGC wastes from coal-fired plants. This 24-month project is expected to be underway later in 1979.

EPRI is sponsoring a program of monitoring the waste disposal site at the Conesville plant of Columbus & Southern Ohio Power Company. This study, which will be underway by late 1979, will be conducted by Michael Baker, Inc. and Battelle Columbus Laboratories.

The above two studies are expected to provide substantial data on leaching from ponds and other modes of FGC waste disposal. Proposed RCRA guidelines [8] provide some guidelines on appropriate impoundment design.

2.2.2 Dry Disposal

2.2.2.1 Description of Practice

Dry disposal methods may involve any one of the following modes:

- Dry collection and direct disposal of coal ash and, in the future, dry sorbent FGD wastes,
- Interim ponding followed by excavation and landfilling,
- Mechanical dewatering and direct landfilling of FGC wastes,
- Blending with fly ash and direct landfilling of FGD wastes, and
- Stabilization through the use of additives (non-proprietary or otherwise) prior to landfilling.

Operation of a dry disposal system usually involves up to four basic steps:

- Collection/storage,
- Processing (dewatering, ash blending, stabilization, etc.),
- Transfer/storage/transport, and
- Placement and compaction.

The exact nature of a particular operation will depend primarily upon the type of waste and the location of the disposal site. Where disposal sites are at some distance from the power plant (or waste processing plant), transport of dry, dewatered, or processed waste is usually accomplished by open, rear-dump trucks although in at least one case, a dedicated rail-haul system is being used. Interfacing a trucking operation with waste production and disposal frequently requires waste transfer/storage systems, especially at the power plant (or processing plant). In the simplest cases, this can involve directly filling of trucks with discharged wastes via feeder chutes or hopper bins (although provisions for emergency waste storage areas would be required). This approach frequently is used in dry ash disposal and some codisposal operations. In some cases, though, particularly for FGD/ash codisposal and disposal of stabilized wastes, it is necessary to provide interim storage piles from which the trucks are loaded with front-end loaders. This usually requires use of stacking conveyors.

Where the disposal site is adjacent to the power plant, the trucking of the wastes can be minimized or possibly eliminated by locating the FGC waste dewatering or processing plant at the disposal site. Stacking conveyors can then be used to move the wastes into the disposal areas and dozers and earth-moving equipment used to spread and compact the wastes. This is usually practical only for relatively small disposal operations.

In general, operations at the landfill area involve dumping, spreading and compaction. Usually, only small sections are worked at any one time. The wastes are layered in one- to three-foot lifts with spreading and compaction most commonly accomplished using dozers. In some cases, fly ash (and bottom ash) and FGD waste can be codisposed without prior blending. In such operations, the ash and FGD wastes would be placed in alternate layers.

Dry Disposal of Ash

Coal ash (fly ash and, if necessary, bottom ash although the latter practice is not common) can be handled in a dry state. In such cases, the ash is conveyed pneumatically from the electrostatic precipitator or bag filter to storage silos for intermittent transfer for disposal.

Storage silos may be of carbon steel or hollow concrete stave construction. Flat bottom silos are equipped with aeration stones or slides to fluidize dust and induce flow to the discharge outlets. Motor driven blowers supply the fluidizing air. Heaters may be required to prevent moisture from forming in the silo. Silos are provided with bag vent filters to prevent the discharge of dust along with displaced air as the silo is being filled. Alternately, venting can be provided by a duct from the silo roof back to the precipitator inlet. In some cases, it may be necessary to install a low pressure blower in the vent duct to overcome losses which might prevent proper release of air and cause pressure buildup in the silo or dropout of fly ash in the duct.

Fly ash normally is deposited in trucks or railroad cars for transport to a dump area. In such cases, it is necessary to wet the dust to prevent it from blowing off conveyances during transportation.

This is accomplished by means of conditioners which may be horizontal or vertical rotary pug-mills. These units require water under pressures of about 80 psi. Alternately, if ash is deposited close to the plant area, it may be mixed with water at the vacuum producer part of the handling system.

The wetted coal ash is deposited in the fill site and spread by dozers in small lifts 0.3 to 1 meter (about 3 feet) and compacted by wide track dozers or heavy rollers. When and where needed, water trucks are employed during disposal operations at the site to control fugitive dust. The lifts are built up to a total ultimate fill height which will be site specific but which may range from 9 meters (about 30 feet) to over 25 meters (over 82 feet).

In the future, disposal of dry sorbent FGD wastes is expected to follow analogous operations. Dry sorbent wastes are expected to be fine, dry solids similar to fly ash (dry sorbent wastes may contain FGD wastes and fly ash for simultaneous removal will be practiced).

Interim Ponding

In this approach, the FGC waste is settled in storage ponds and the supernate is recycled to process or otherwise lost through evaporation. The pond may be reclaimed or, when the material is a moist solid, may be excavated and landfilled in a permanent site. This method has been used for disposal of sluiced ash from dry collectors and in at least some cases for disposal of wastes from wet particulate scrubbing systems [6]. The interim ponding/excavation method is most applicable in arid regions; it will find only limited use for FGC waste disposal in the future. Examples of interim ponding of FGC wastes are at the Colstrip plant of Montana Power and the Cholla plant of Arizona Public Service. The Four Corners plant of Arizona Public Services employs interim ponding for coal ash.

Mechanical Dewatering and Landfilling

Mechanical dewatering methods, including vacuum filtration or centrifugation, may remove enough water from FGC wastes to allow direct landfill disposal without additional processing (e.g., ash blending or stabilization. This method of disposal is applicable to:

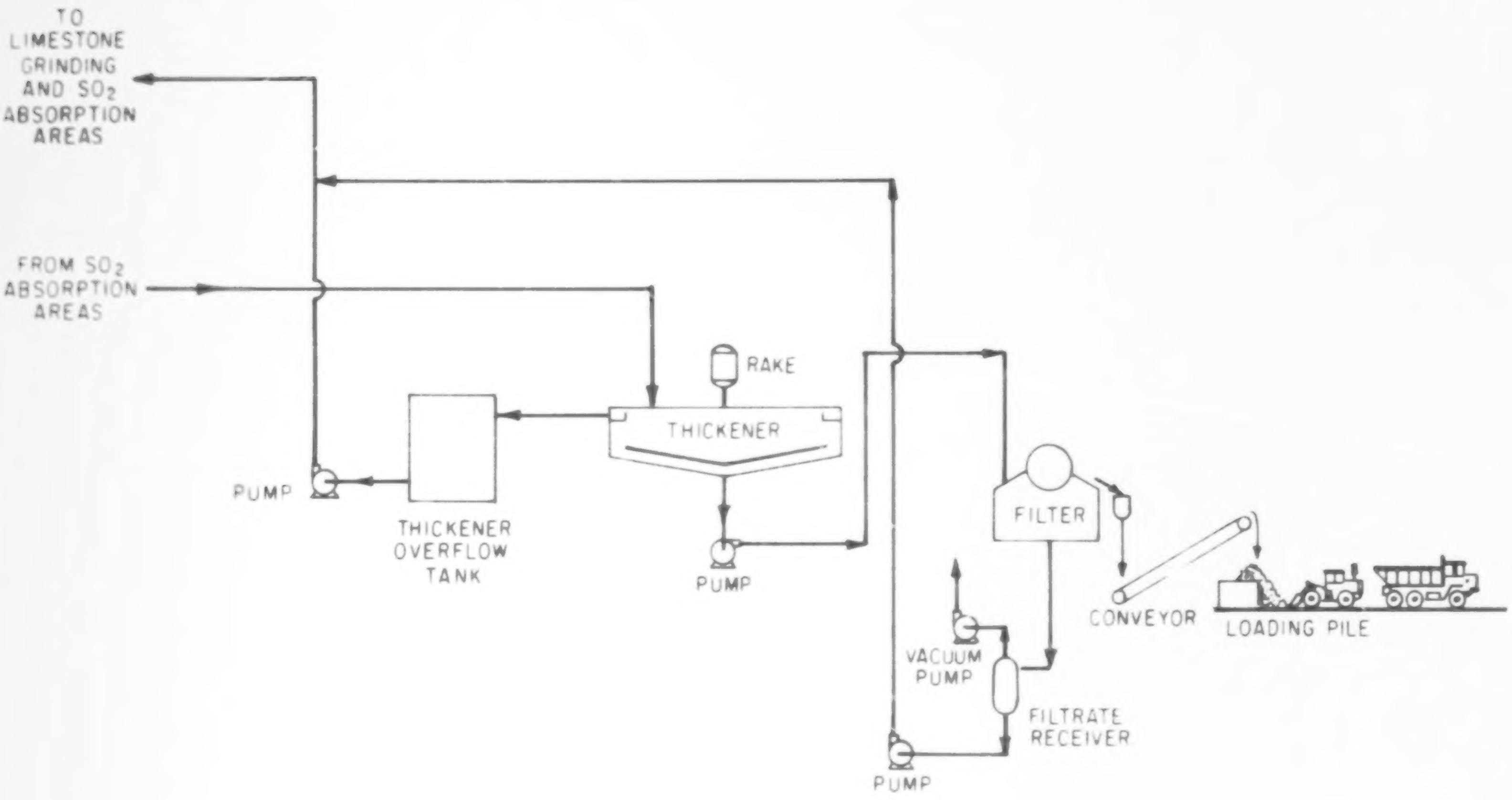
- Sluiced fly ash from dry collection systems where the ash is dewatered in settling/decantation bins,
- FGD wastes from systems producing sulfate-rich wastes,
- FGD wastes from systems employing forced oxidation to produce gypsum, and
- FGD wastes from dual alkali systems, especially those employing simultaneous fly ash and SO_2 control (these wastes are sometimes more readily dewatered than sulfite-rich wastes from conventional direct lime or limestone scrubbing systems) [22].

An example of such a system is installed at the Caterpillar Engine Plant at Mossville, Illinois [9]. In this 56 MW unit burning 2-1/2% S coal, an FMC dual alkali system employing sodium carbonate/hydrated lime produces a cake of 50-70% solids in vacuum filters; the cake is placed directly in a landfill.

Improvements in dewatering behavior and crystal morphology through control of scrubber operation may make this method more applicable. A typical generic flowsheet for sulfate-rich (or gypsum) waste is shown in Figure 2.8.

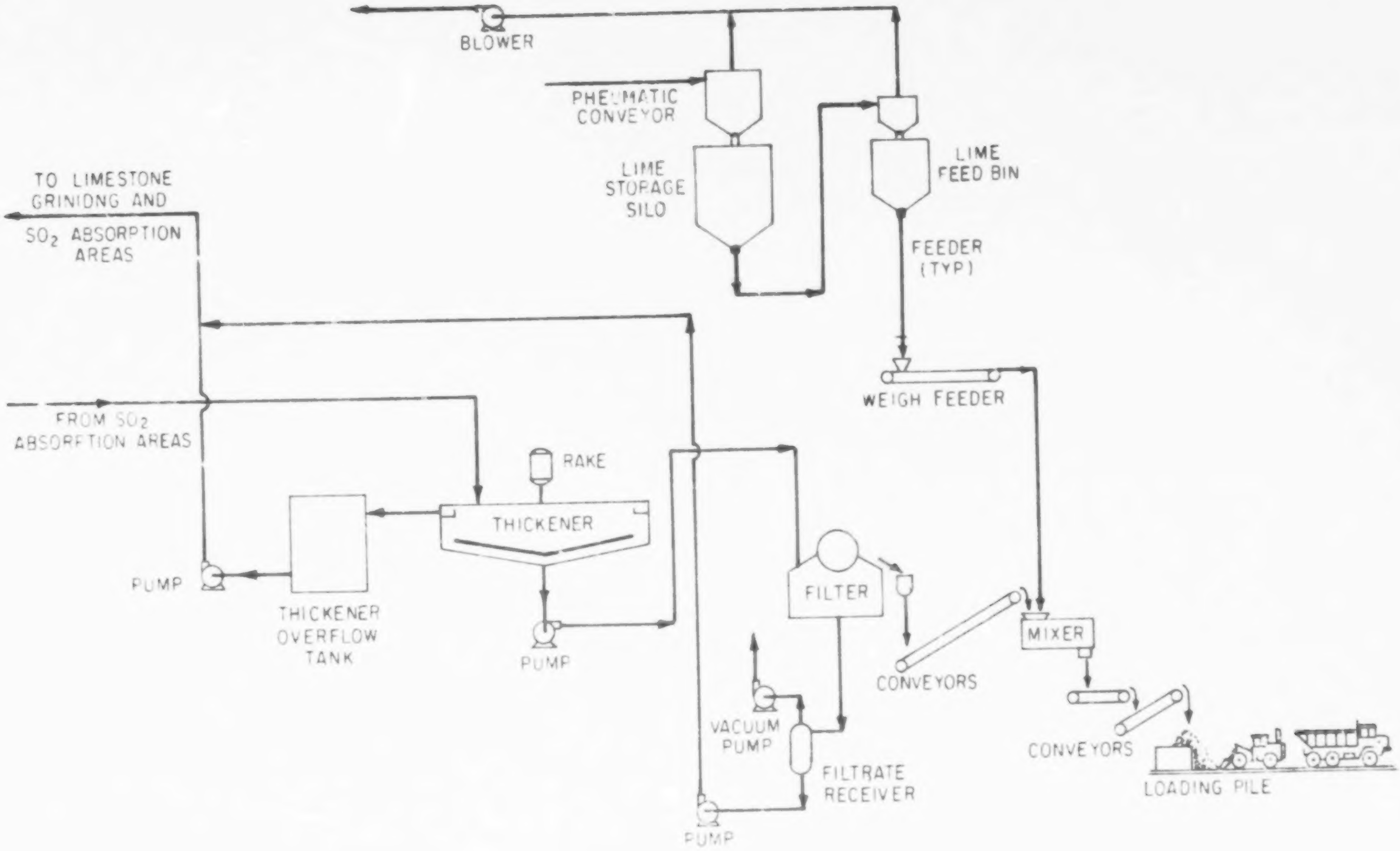
Blending with Fly Ash

Usually it is difficult and expensive to dewater FGD wastes, particularly sulfite-rich or mixed sulfate/sulfite wastes. An alternative to produce a moist cake suitable for landfilling is to dewater to some extent and then mix the dewatered waste with fly ash[22,23] or soil [24] to produce a mixture with lower moisture content than the dewatered waste alone and which can be more readily handled. A typical flowsheet of such a blending scheme is shown in Figure 2.9. Care is required in designing the system, because the addition of fly ash in the dry form may lower the moisture content below that needed for optimum compaction in the landfill. The reactivity of the ash also needs to be considered in system design.


TO LIMESTONE GRINDING AND SO2 ABSORPTION AREAS
FROM SO2 ABSORPTION AREAS
RAKE
THICKENER
PUMP
THICKENER OVERFLOW TANK
PUMP
FILTER
CONVEYOR
LOADING PILE
VACUUM PUMP
FILTRATE RECEIVER
PUMP

Source: [23]

Figure 2.8 Typical Landfill Scheme for Sulfate-Rich or Gypsum Wastes


BLOWER
PNEUMATIC CONVEYOR
LIME STORAGE SILO
LIME FEED BIN
FEEDER (TYP)
TO LIMESTONE GRINIDNG AND SO2 ABSORPTION AREAS
WEIGH FEEDER
FROM SO2 ABSORPTION AREAS
RAKE
THICKENER
PUMP
THICKENER OVERFLOW TANK
PUMP
FILTER
CONVEYORS
MIXER
VACUUM PUMP
FILTRATE RECEIVER
PUMP
CONVEYORS
LOADING PILE

Source: [23]

Figure 2.9 Untreated Waste Fly Ash Blending

Some scrubber vendors like Combustion Engineering [25], Research Cottrell [26], and others are offering assistance in such design and construction.

Among the systems employing blending with fly ash is the Martins Lake Station of Texas Utilities (two 795-MW lignite-fired boilers). In this system, dewatering of the thickener underflow is accomplished in centrifuges followed by blending with dry fly ash to produce a mixture that can be handled for disposal. The solids content of the mixture is 85% and permeability is reported to be 10^{-5} to 10^{-6} cm/sec. The wastes are returned via a dedicated rail-haul system to the surface mine for disposal. At the mine, the wastes are dumped directly from the rail cars and compacted. As disposal progresses, the rail tracks are moved to new areas of the mine.

Co-Disposal of Ash and FGD Wastes

In an engineering context, the advantages of co-disposal seem to outweigh the disadvantages. It may be easier to handle the sludge-ash mix than to handle (transport, place, compact, etc.) waste or ash alone. Fill construction would be easier using one material rather than two at the same site (mixed wastes versus layers of waste between ash) and using one material in one fill rather than two separate fills, at the same site or at separate sites. The mix of ash and wastes (sludge) should be less compressible and stronger than wastes alone, and less subject to erosion than ash alone. The mix of ash and wastes may be self-hardening or it may require less fixative in a mixed fill than in separate fills.

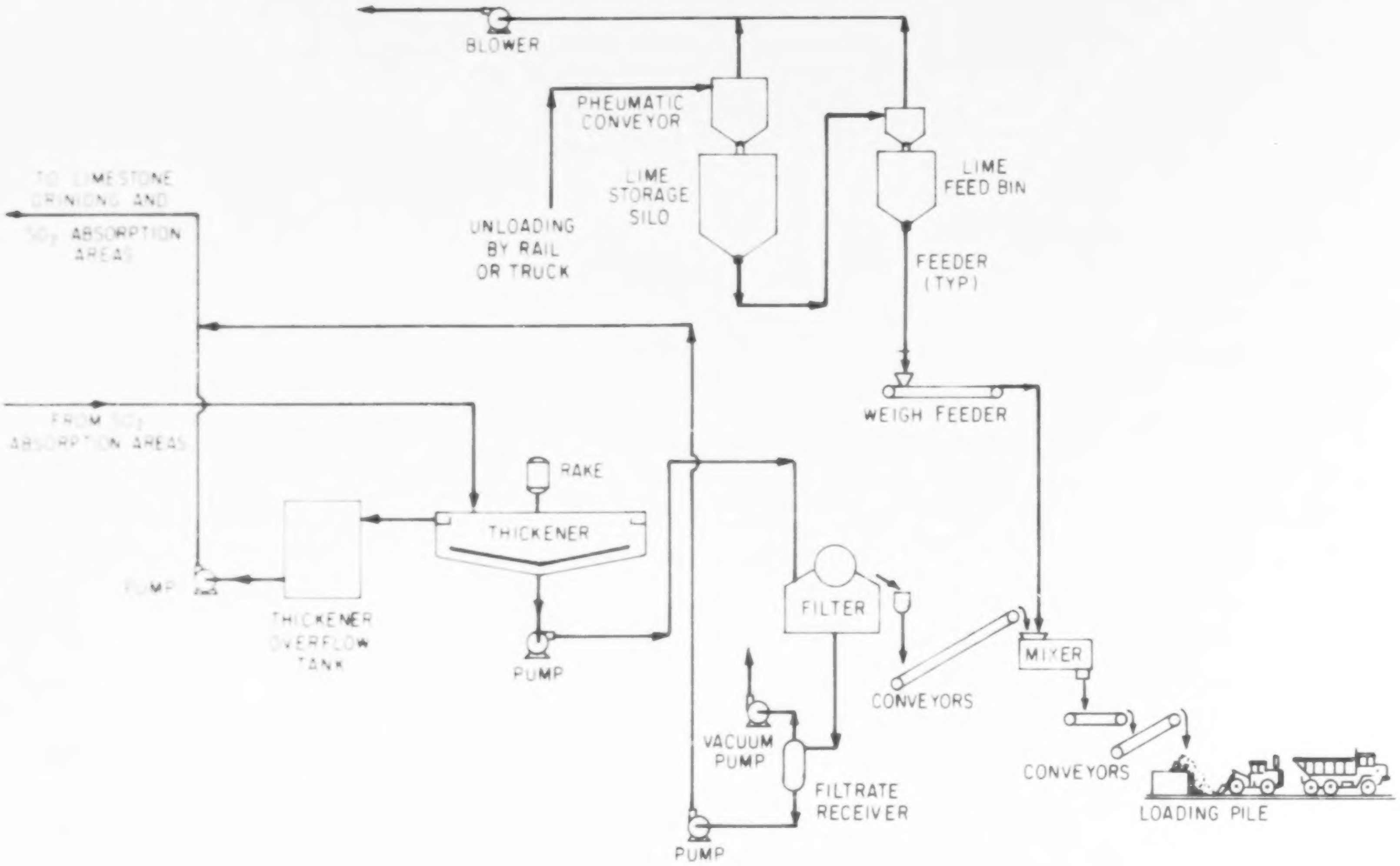
A possible disadvantage could be an increase in permeability (ash-waste mix versus waste alone) with potential for more infiltration and leaching. Another disadvantage is that the mix could be more difficult to transport than is ash alone (but easier than waste alone, at the same solids content).

Stabilization Additives

In this method of dry disposal, lime and fly ash or other stabilization additives are added to dewatered wastes prior to disposal. A generic flowsheet of this scheme is shown in Figure 2.10 based on descriptions of the IUCS stabilization process.

In a stabilization process, cementitious additives produce pozzolanic reactions that result in increased structural integrity in the wastes. This chemical process continues after placement. Typically, for dry impoundment type of disposal, the wastes are thickened and dewatered to a high solids content and blended with fly ash and lime, thus forming a material with cementitious properties. This material is transported to the disposal site where it is spread on the ground in 0.3 to 1 meter (1 foot to 3 foot) lifts and compacted by wide track dozers, heavy rollers or other equipment. Layering proceeds in 0.3 to 1 meter lifts in segments of the site. The ultimate height of a disposal fill is site specific but may be as high as 25 meters (82 feet) or more. A properly designed and operated dry impoundment system employing stabilized wastes may enhance the value of the disposal site after termination or at least permit post operational use.

An example of the application of waste stabilization and dry impoundment is the system at the Conesville Station of Columbus & Southern Ohio. The Conesville generating station is a mine-mouth power plant located on the Muskingum River near Coshocton, Ohio. The power plant consists of six high sulfur, coal-fired boilers with high efficiency electrostatic precipitators for particulate control, totaling about 2,000 MW of generating capacity. Two boilers (Units 5 and 6), each with a capacity of about 400 MW, are equipped with direct lime scrubbing systems for SO_2 control. The FGD systems (by the Air Correction Division of UOP) for each boiler consist of two 200-MW TCA (turbulent contact absorber) scrubbing modules which utilize thiosorbic lime as the scrubbing reagent. Each pair of scrubber modules has a separate thickener for initial dewatering of the waste solids. The waste calcium-sulfur salts thickened to 25-35% solids (35% solids design) are pumped to the waste processing plant designed by IUCS for further dewatering and stabilization by admixture with fly ash and lime. The stabilized wastes are then disposed of in a section of the existing ash pond.


BLOWER
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UNLOADING BY RAIL OR TRUCK
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PUMP
THICKENER OVERFLOW TANK
PUMP
FILTER
CONVEYORS
MIXER
VACUUM PUMP
FILTRATE RECEIVER
CONVEYORS
LOADING PILE
PUMP

Source: Description of the IUCS Stabilization Process*[26]

Figure 2.10 FGC Waste Disposal Using a Stabilization Process*

adjacent to the plant. The disposal operation is essentially a dry impoundment using standard earth-moving equipment. Figure 2.11 shows an outline of the process. It should be noted that this system incorporates essentially 100% redundancy of all major equipment which would not normally be required for most systems.

2.2.2.2 Engineering Considerations in Dry Disposal

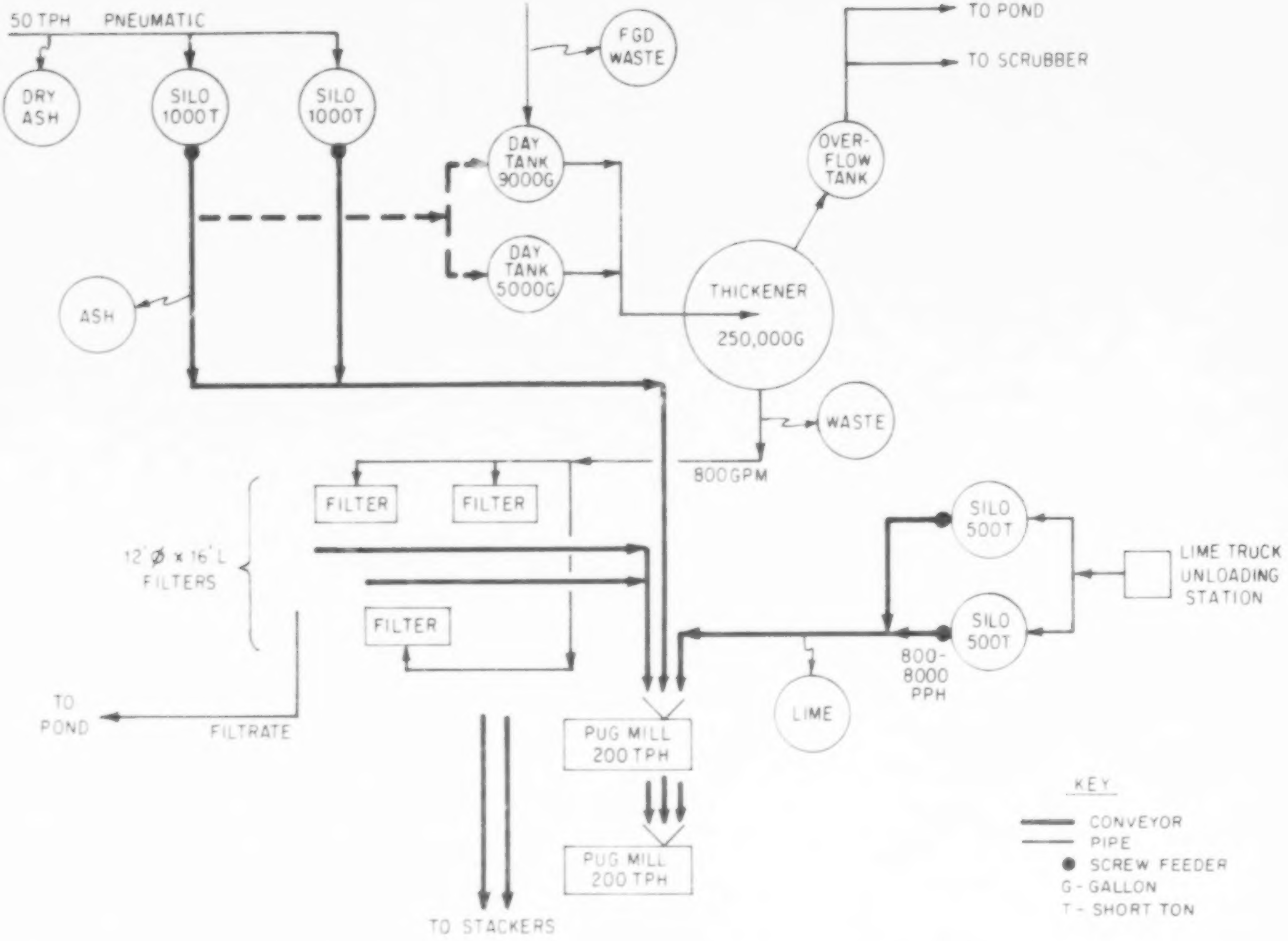
Detailed design of FGC waste treatment and dry disposal operations is site and system specific. However, some broad engineering considerations are discussed below to aid in defining environmental impact issues. These considerations are also broadly valid for mine disposal.

Physical Stability

Physical instability is a potential problem for all FGC wastes, including stabilized wastes. Geometric factors such as height and slope angle in a waste/ash fill are interrelated; stability depends on the combination of fill height, slope angle, wastes density, degree of saturation, effective cohesion, effective angle of shearing resistance, and behavior during shearing (dilatant versus densifying). For a given material, safe fill height decreases with increasing slope angle. For proper design, data are required in which maximum safe fill height is related to slope angle and soil shearing behavior. Such relationships have not been developed yet for FGC wastes because adequate data from proper tests (triaxial compression tests on consolidated samples with measurement of porewater pressures) have not been available.

Underlying materials may lead to instability of a waste deposit if the stresses in those materials exceed the strength of the materials under those loading conditions; i.e., failure may occur because of the weakness of the underlying strata (a basal failure in geotechnical terminology). Weak compressible soils would be potential problem materials in this context (e.g., normally consolidated clays).

Erosion of cover materials could be important. If a relatively tight (low permeability) cover soil or seal layer were removed through erosion and if more pervious wastes were exposed by this erosion, infiltration of precipitation or surface runoff into the wastes deposit could



50 TPH
PNEUMATIC
DRY ASH
SILO 1000T
SILO 1000T
FGD WASTE
TO POND
TO SCRUBBER
DAY TANK 9000G
DAY TANK 5000G
OVER-FLOW TANK
ASH
THICKENER
250,000G
WASTE
800GPM
FILTER
FILTER
12'Ø x 16'L FILTERS
FILTER
SILO 500T
SILO 500T
LIME TRUCK UNLOADING STATION
800-8000 PPH
LIME
TO POND
FILTRATE
PUG MILL 200 TPH
PUG MILL 200 TPH
TO STACKERS
KEY
CONVEYOR
PIPE
● SCREW FEEDER
G - GALLON
T - SHORT TON

Source: Arthur D. Little, Inc.

Figure 2.11 Schematic of IUCS "Stabilization" Process at Conesville

be increased. Increased infiltration could lead to saturation of wastes previously unsaturated and could cause generation of significant porewater pressures. Saturation would increase the weight of the wastes and porewater pressure generation would decrease effective stress thus decreasing the strength of the wastes deposit. Both factors tend to lead to sliding/slumping. In any case, erosion of cover materials has been studied extensively and is a function of material erodibility, which depends principally on particle sizes, particle shape and interparticle cohesion.

On the other hand, placement of cover material over a wastes deposit may cause a mass failure if the added load (surcharge) exceeds the bearing capacity of the filled material. This could occur with surcharge on a wastes slope or with concentrated loads due to inequalities in surcharge loading.

Compaction

Instability problems may be ameliorated by compaction since compaction may produce several changes: voids may be eliminated (between chunks, not between individual particles); wastes density may be increased; particles moved closer together may be bonded more effectively in stabilization reactions; and effective stress and residual total stress levels may be increased. If the wastes resemble sandy soils, an increase in density during compaction may create an important increase in angle of shearing resistance. Compressibility also would be decreased by an increase in density. Compaction of natural soils tends to create suction in the water between soil particles if the soil is unsaturated and tends to swell after removal of the compaction pressure. This effect probably would not be as important for sand-like wastes (e.g., some sulfate-rich wastes) as for more fine-grained platy-particle wastes. The increase in density would probably yield greater strength since the fine-grained wastes would be changed in shearing behavior to more dilatant behavior. Saturation of unsaturated compacted wastes would eliminate the beneficial suction in the porewater and decrease the strength of the wastes, but the benefit of increased density could be significant.

Physical factors such as compaction effects also may alter with time. If the wastes are saturated, with low solids content, consolidation may occur with significant increase in solids content, stiffness and strength; this may be significant for thickener underflow consistencies. Increase in density (and consequent increase in strength) created by compaction should not disappear, but long-term saturation can potentially dissipate suction effects (and consequent increase in strength) created during compaction. Dissipation of suction effects would have most effect near the surface of a waste deposit because, at depth, overburden pressures could create interparticle stresses equal to the interparticle stresses created by suction in the porewater.

The stability of settled sulfite wastes under compaction equipment will vary with the solids content of the wastes (assuming no chemical stabilization of wastes) and probably with the type of compaction equipment (static, rubber-tired, steel roller, sheepsfoot, vibratory, etc.). Experience at the Scholz plant indicated it was necessary to dewater waste to 70-75% solids content before compaction could be accomplished. Sulfite wastes tested to date may be incapable of supporting compaction equipment of any kind unless such high solids contents are achieved first. Liquefaction may be a more serious threat in sulfate wastes, especially under vibratory loading. Field tests are required for an answer to this question.

2.2.2.3 Climate

Climate could affect the stability of a wastes deposit in several ways. The total amount of rainfall and the intensity of rainfall both affect surface erosion, but these factors influence the rate of erosion; i.e., erodible materials will erode if wind and rain act on them but increase in amount/duration and intensity of wind and rain will increase the rate of surface erosion. Of course, as mentioned above, infiltration of water into wastes deposits can lead to saturation, decrease in apparent strength, and, possibly, to failure. This would be most likely to occur with wastes of highest permeability in an unsaturated condition, but it could occur in any improperly designed FGC waste deposit.

Freeze-thaw cycles could have several effects. Stabilization reactions could be retarded, disrupted or destroyed by an episode of freezing soon after mixing and placement. Freezing could produce cracks in the near-surface layers of a wastes deposit (frost polygon behavior). Cracks in the wastes deposit could yield greater mass permeability and infiltration rate even though waste blocks between cracks had been compressed and even dewatered. In a fill created in layers over a number of years, freeze-thaw effects on temporarily exposed faces and surfaces could produce horizontal layers through the finished deposit, with high "crack" permeability in such layers (this type of structure is common in masses of alluvium along large rivers). Increased permeability could lead to more formation of leachate. On the other hand, freeze-thaw cycles may be effective at some sites in dewatering surface layers. The problems of crack formation could be ameliorated by compaction of the thawed material after maximum possible evaporative dewatering and before placement of additional thickness of wastes. Freeze-thaw effects require investigation.

2.2.2.4 System Design and Post-closure Land Use

Often it is difficult to specify the ultimate use of the land on which FGC waste disposal is planned or practiced. However, it is important to recognize engineering constraints on post-closure land use. Post-closure land use would tend to be limited by nature of the loads created or by the sensitive nature of the structures or facilities built on the wastes fill. For example, placement of some sort of fill in a uniform layer over the entire waste deposit should be feasible, but imposition of concentrated loads (e.g., footings in a building) may cause bearing failure with rapid plunging of the loaded element into the wastes. Vibratory loads as from machinery foundations could have disastrous effects on unfixed wastes. The rate of application of load also is extremely important--loads applied slowly may allow consolidation of the wastes during loading, yielding higher strength than for material loaded rapidly. Rapid application of load increases shearing stresses and may decrease shearing resistance if the structure of the wastes is disturbed (collapse or remolding).

The nature of the supported use also is important. A park built on cover soil over FGC wastes would not be affected seriously by wastes settlement. A low, flexible structure like a warehouse would exert low loads and could tolerate greater total and differential settlements than could a structure like a boiler-turbine-generator complex.

Uses of adjacent land could be restricted by access or geometry limitations (e.g., difficulty in building access roads across wastes deposits) or by consideration of possible failure of wastes retention structure, or by pollution effects (losing the use of groundwater through pollution by leachate from FGC wastes).

In the choice of a site for disposal, it is well to note that any land could be used for wastes disposal, with proper engineering design, but the choice to dispose of FGC wastes at a given site might be based on the concept of "best and highest sequential use" with all technical, economic and environmental factors considered. Obviously, waste land areas with irregular topography (for ease of containment and a source of cover soil) and highly impervious subsoils would be ideal. Valuable, flat or uniformly sloping areas with highly pervious soils and scarce, pure (thus valuable) groundwater would be poor locations for disposal sites. Wetlands would be a poor choice.

Runoff-Related Considerations

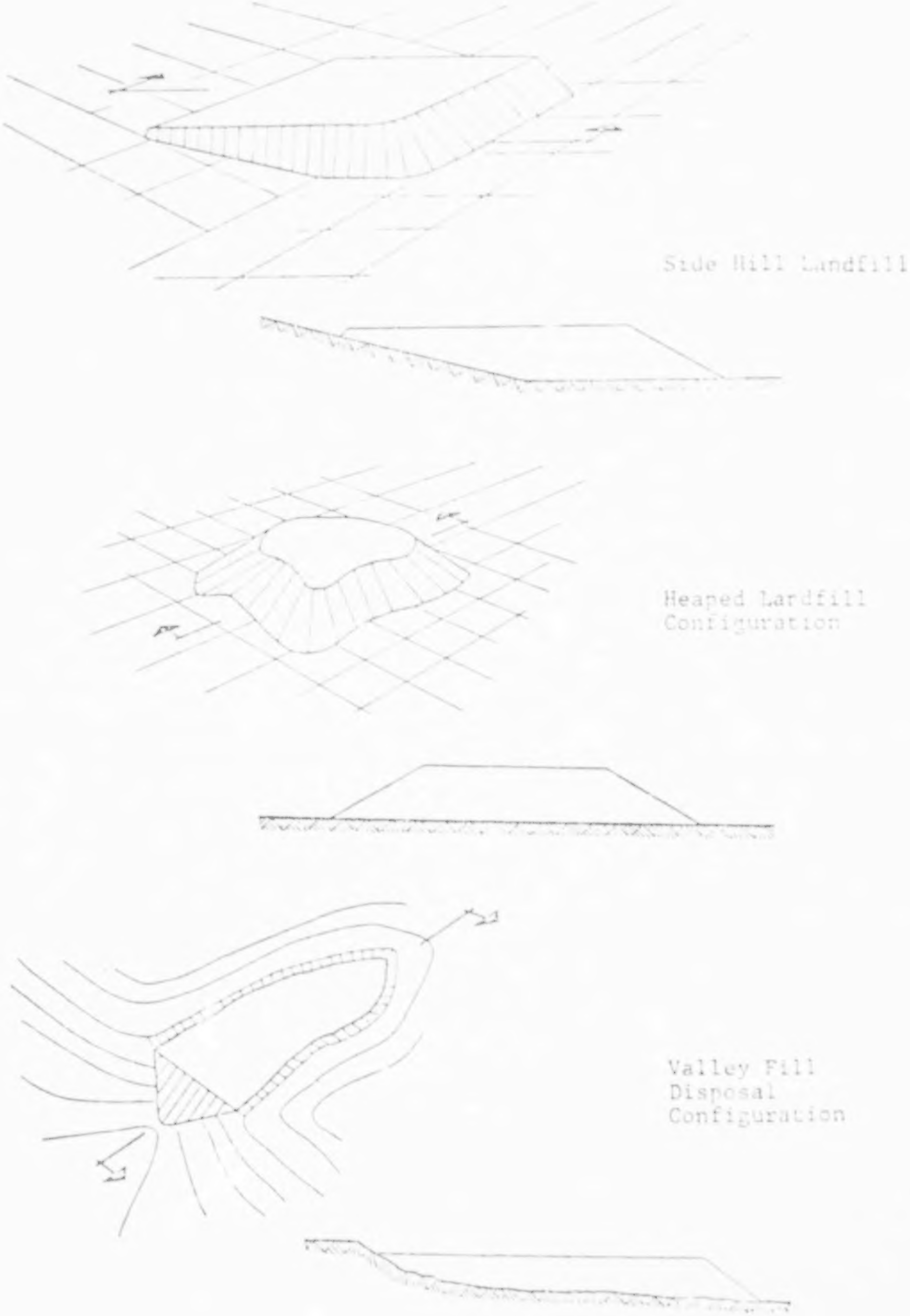
To limit water losses by runoff from a wastes deposit, grading and drainage during construction could be employed as in any other construction activity. After completion of the deposit, a cover soil is chosen to limit infiltration; a soil consisting of a mixture of clay, silt and sand fractions is better for this purpose than a material of uniform grain size, no matter what the average grain size. Water recycle could certainly be employed; surface runoff caught in temporary retention basins could be piped back to the FGC system.

To limit water losses by leachate, water infiltration into the fill is minimized by the techniques mentioned above, the water content of the wastes is minimized by dewatering prior to placement and a seal layer is prepared in the bottom of the fill area prior to wastes placement. Below the bottom seal, a pervious drainage layer could be constructed to surround the wastes deposit; this pervious layer would collect leachate and carry it to a central sump. From the sump, the leachate could be recycled to the scrubber (if feasible) or it could be sprayed on the surface of the fill to utilize evaporation as a means to decrease leachate quantity, or it could be piped to a treatment plant. If the natural subsoils at the disposal site were very pervious, a seal layer could be required below the drainage layer.

2.2.2.5 Design of Landfill

Landfill design can be based on many configurations. Three broad generic configurations are shown in Figure 2.12. Some pertinent comments are:

- The structurally simplest form of landfill which may be utilized with level terrain is the heaped landfill. Even though this design is simplest in terms of site preparation and may offer advantages in terms of slope stability and groundwater pollution, it is often aesthetically undesirable.
- Side hill design is advantageous and often utilized in areas of hilly terrain where the natural slope of one side of a hill or valley may provide containment. The side hill landfill must be prepared properly to ensure stability.
- The valley fill design, which is the most common type of landfill used, is often the most complex in terms of original site preparation. Natural valleys or ravines are often sources of surface water runoff and may have springs along side slopes. In such cases, surface water and groundwater control is usually necessary to avoid accumulation of water and the development of a leachate problem. Drainage must be provided and, in some cases, hydrologic modifications to divert water flow around the landfill are necessary.



Side Hill Landfill

Heaped Landfill Configuration

Valley Fill Disposal Configuration

Source: [7]

Figure 2.12 General Landfill Designs

Design of a managed operation like a landfill requires adequate data on the engineering properties of the waste and of the soils at the site. Laboratory tests give indications of the shearing behavior, strength and compressibility of wastes. To maximize stability, the factor of safety is normally set between 1.0 and 3.0, with the value chosen depending on the consequences of failure. Then, using appropriate values of shear strength parameters obtained in laboratory tests, the designer would obtain combinations of fill height and slope angle corresponding to the selected factor of safety. The steeper the slope angle, the lower the maximum safe fill height. No absolute maxima or minima exist. Also, underlying strata properties and topography influence this analysis. Disposal techniques influence stresses, porewater pressures and shear strength parameters. A proper design is necessarily site specific. Proper landfill design requires control of both leachate movement and runoff. Stabilization processes reduce permeability of the waste. To achieve full environmental benefits from such processing and compaction of the wastes, proper design of the landfill to control runoff is necessary. Conventional runoff control practice in the construction industry consists of retaining runoff in temporary retention basins to settle suspended solids prior to discharge or other use.

For a brief overview of the data base on land disposal of FGC wastes, the reader is referred to [28].

2.2.3 Mine Disposal of FGC Wastes

2.2.3.1 Introduction

While mines have been used for the disposal of coal ash and mine tailings for many years, they are only now being seriously considered for the disposal of FGC wastes. There are currently over 15,000 mines throughout the United States which together produce over 0.5 billion tons of coal and 2.5 billion tons of metallic and nonmetallic minerals each year. About one-third of the mines individually produce over 100,000 tons annually, mines large enough to handle the quantity of FGC wastes produced by a normal utility boiler. Such mines represent an enormous capacity for the disposal of these wastes.

However, much of the capacity is clearly not suitable for FGC waste disposal. The method of mining, for example, can preclude practical waste disposal operations. Underground mining which employs caving or cut-and-fill techniques leave little available void for waste disposal. In open-pit mining, overburden is often removed from the mine area, and the mineral is mined downward from the surface in benches, or the mining operation may follow the ore strata downdip from its surface outcrop, which requires that the area mined be left open for access of haulage vehicles.

The four different categories of mines which appear to provide the greatest potential for the disposal of large quantities of FGC waste, at least with regard to the overall technical feasibility are [29]:

- Surface coal mines,
- Underground room-and-pillar coal mines,
- Underground room-and-pillar limestone mines, and
- Underground room-and-pillar lead/zinc mines.

Of the four categories of mines noted above, coal mines, and in particular interior and western surface area coal mines, are the most likely candidates for waste disposal. Coal mines offer the greatest capacity for disposal, and they are frequently tied directly to power plants. In fact, many new coal-fired power plants are "mine-mouth" (located adjacent to the mine within a few miles) and the mine provides a dedicated coal supply. Since the quantity (volume) of FGC wastes produced is considerably less than the amount of coal burned, such mines usually would have the capacity for disposal throughout the life of the power plant.

2.2.3.2 Surface Coal Mines

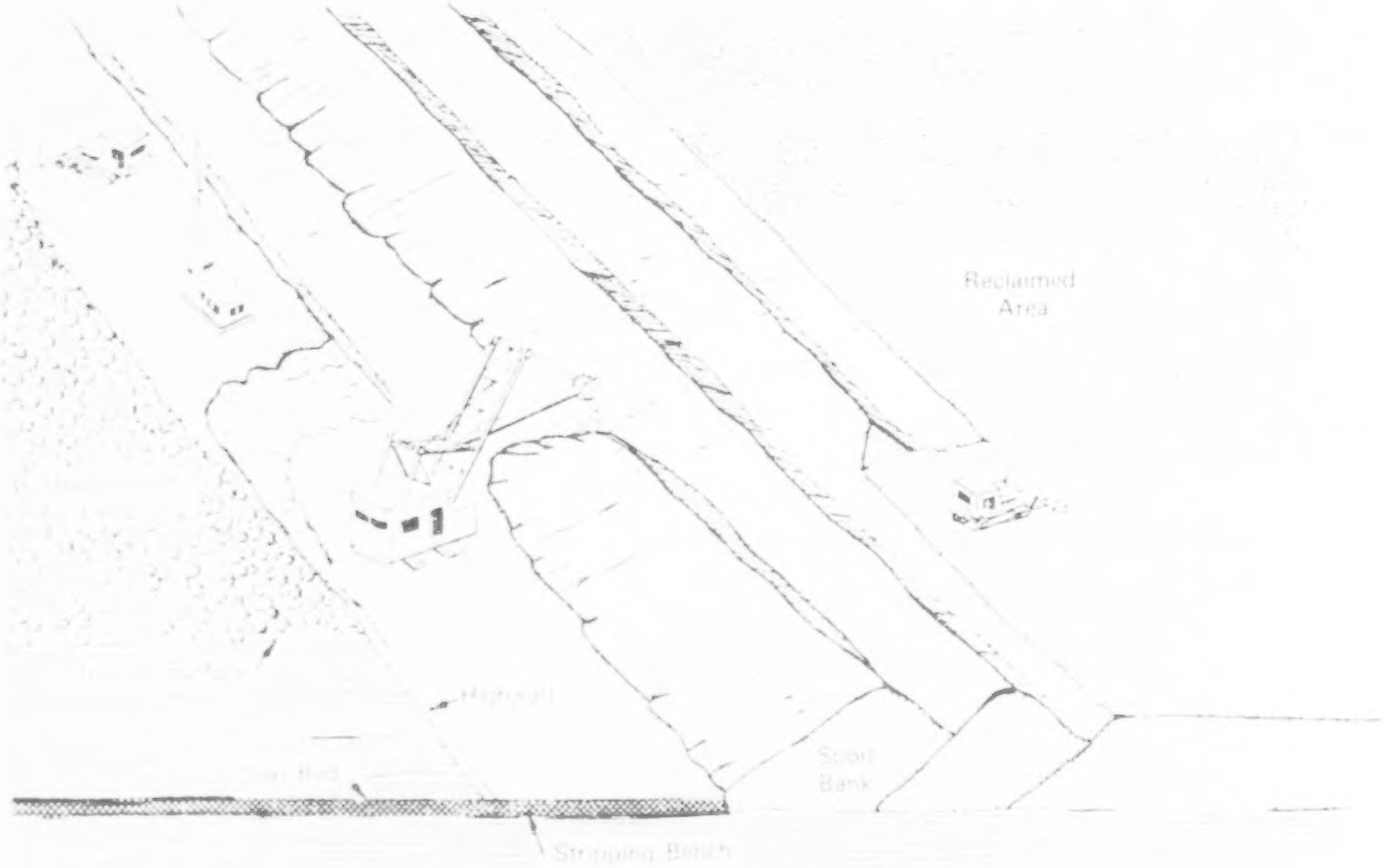
Description of Mining Operations

The conventional method for surface mining of coal is called "strip mining." Mining practice in strip coal mines mostly involves the use of draglines and shovels for overburden removal, smaller shovels and front-end loaders for coal digging, and trucks for coal hauling. In a few cases, scrapers and bucket wheel excavators are used in softer overburdens. However, in strip coal mines where the overburden is relatively soft or can be loosened somewhat by gentle blasting, the dragline is the preferred machine to use for digging and casting the overburden. If the formations over the coal seam are hard and compact, and tend to break into blocky or hard-to-handle aggregates of blocky chunks, then large shovels are preferred. Now, more than half the surface mining of coal in the United States involves draglines rather than shovels.

There are basically two different types of strip mining. For relatively flat or level areas, coal is mined by "area stripping." Area stripping is commonplace in the Western and Interior coal mining regions. On steep slopes, the method used is called "contour stripping." Such steep slope conditions prevail in the Eastern coal region.

A typical area strip mining operation involving the use of a shovel for removal of the overburden is shown in Figure 2.11. In a typical case, the shovel, sitting on the floor of the pit on top of the unmined coal, removes the overburden and dumps it to the side in the previous cut from which the coal has been extracted, forming what is called a "spoil bank." The coal extraction operation then advances behind the shovel. This may involve blasting prior to digging and loading the coal onto trucks using smaller shovels and/or front-end loaders.

The area of the spoil banks is reclaimed using dozers, graders, and standard earth-moving equipment. Reclamation usually involves flattening of the spoil banks followed by covering with a layer of topsoil and seeding. The reclamation process usually progresses concurrent with the mining operation, but at two or three spoil banks removed from the exposed


Reclaimed Area
Highwall
Coal Bed
Spoil Bank
Stripping Bench

Source: [29]

Figure 2.13 Area Strip Mining With Concurrent Reclamation

pit to ensure stability of the spoil banks adjacent to the working areas. The topsoil used in the reclamation process can either be that originally present or soil imported from nearby areas (or a combination of both). The process of removing or obtaining topsoil and storing it adds another step to the mining operation and must be coordinated with the other activities. To provide some perspective on strip mines in various regions, one may note [29]:

- Interior surface mines produce 1.5 to 2.0 million tons of coal annually and seams vary from 0.8 to 2.1 meters (2-1/2 to 7 ft) thick. Width of the pit is often 15 to 30 meters (50 to 100 ft) while a typical length is 0.6 to 1.2 kilometers (1-2 miles).
- Western surface mines are usually larger. Seams may be up to 30 meters (100 ft) thick.

Contour strip mining is practiced almost exclusively in the Eastern region (particularly Appalachia). In conventional contour stripping, spoil or waste is stripped and dumped downhill from the cut. This frequently causes water runoff erosion problems with damage to property holders below. Reclaiming can then be more difficult since waste has to be moved back up-hill again. A variation in this conventional approach, known as the "block" ("haulback") method of mining, solves many of these problems. In the haulback method, spoil is moved horizontally from the working area to the mined-out cut. This requires mobile equipment such as bulldozers, scrapers, front-end loaders, and trucks. The production from individual eastern mines is considerably less. Eastern surface contour mine production ranges from 0.01 to 1.5 million tons per year. Coal seam thicknesses vary from 0.8 to about 2.1 meters (about 2-1/2 to 7 ft) and are usually horizontal. Contour stripping method of mining is less amenable to FGC waste disposal than area stripping method described earlier.

FGC Waste Placement

In general, inactive surface mines may be less promising than active mines for FGC waste disposal. Unreclaimed surface mines can be used for disposal of wastes between remaining spoil banks, and these may offer suitable sites for disposal. However, because of recent surface mine reclamation legislation, the number of sites and total capacity for wastes available in the future may be limited.

In active surface mines, there are basically three options for the placement of FGC wastes:

- In the working pit, following coal extraction and prior to return of overburden,
- In the spoil banks, often return of overburden but prior to reclamation, and
- Mixed with or sandwiched between layers of overburden.

In any disposal operation in an active mine, though, the general overriding consideration is that disposal should cause minimal disruption of mining or reclamation activities. This provides a number of constraints on the disposal system.

First, the amount (volume) of FGC waste disposed of in any surface mine should not exceed the amount of coal removed. The objectives of strip mine reclamation include returning the mined terrain to topographic configurations similar to original terrains, and returning significantly more waste to a mine than the coal extracted could slow down the mining and reclamation activities. In most cases, this does not really represent a constraint, since the wastes returned to the mine will be only those resulting from the coal removed. The amount of FGC waste generated from the combustion of coal will be considerably less than the quantity (weight or volume) of coal removed. Depending upon the type of coal, FGC system, and emission standards to be met, the volume of total waste (ash plus calcium-sulfur solids) will vary from less than 10% of the coal burned to slightly over 50%. With Western coals, which are relatively low in sulfur, less than 20% is the rule. With higher sulfur Eastern and Interior coals, the total amount of wastes will typically run 30% or more.

Second, the physical condition (consistency) of the wastes must be amenable to ease of handling, transport, and placement using earth-moving equipment with minimal potential impact of the mining operations. For pit-bottom disposal this means that the wastes at the time of placement or immediately thereafter should have as a minimum the consistency of a soil-like material with little or no liquefaction potential. A slurry-like material or a waste with a tendency to flow either when placed or when overburden is dumped on top could present significant operational problems or unacceptably high costs for containment measures. A little more leeway exists for disposal in V-notches (between spoil banks); however, here again, soil-like materials or relatively cohesive materials that are relatively easily handled and transported will result in the least cost and minimal disruption of reclamation activites. At the least, the wastes must be well filtered (55% solids or higher), admixed with dry fly ash, or treated.

Finally, minimal use should be made of existing mine equipment for transport and placement of the wastes at the mine. Dedicated equipment is preferred and, in most cases, mandatory. In almost all scenarios, waste is most easily placed by truck dumping. The use of coal trucks for this purpose could lead to unacceptable delays in coal mining operations due to the additional time for waste loading and discharging (and possibly cleaning operations). Furthermore, most large mines use large bottom-dump trucks for coal haulage. These are designed to carry as much as 150 tons of coal and are usually constructed of aluminum. Not only might some types of FGC waste corrode the aluminum, but the bottom dumping of wastes would be impractical. These trucks are not designed for ease of manoeuvering, and operating them (or any other equipment) on a freshly dumped layer of waste would be difficult at best. The type of truck used for transport and placement will greatly affect the quantity of waste that can easily be disposed of.

At present there are only two commercial operations involving mine disposal of FGC wastes in surface coal mines--one at Texas Utilities Martin Lake Station and the other at Square Butte's Milton R. Young Station (North Dakota). Both stations fire lignite and involve returning combined fly ash and calcium-sulfur solids from SO_2 removal to the respective

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mines. The operation at the Milton R. Young Power Station is currently an EPA mine disposal demonstration project. At this Baukol-Noonan mine, both pit-bottom and spoil bank disposal are being practiced.

Pit-Bottom Disposal

Pit-bottom dumping is probably the simplest, least disruptive method of surface mine disposal. Transport and placement of the wastes is most easily accomplished using rear-dump trucks. Access to the pit floors is usually good, since roads are maintained in relatively good condition for coal mining and hauling equipment. There is also usually adequate time for waste placement between coal removal and overburden replacement.

Major potential problems are interference with coal removal in the working pit due to instability of adjacent spoil banks caused by the underlying wastes, and the possible congestion in the working pit due to the two-truck transport systems (one for coal and one for wastes). Most of these problems are avoidable by control of waste properties and placement, and proper scheduling of mining and disposal activities. In some cases, it may be advisable to concentrate the waste dumping on the side of the pit farthest from the highwall (against the newly created spoil bank). This will provide an open "buffer" region where no waste exists when the next cut is taken and the overburden dumped on the waste.

V-Notch or Spoil Bank Disposal

V-notch or spoil bank disposal, as with pit-bottom disposal, would involve truck dumping and many of the same constraints with regard to waste characteristics and disposal operations apply. It involves somewhat more effort than pit-bottom disposal, since roads must be cut into the spoil banks at the base of the vees to allow access by waste trucks. This can be relatively easily accomplished in most cases with standard dozers and road grading equipment.

While it requires more effort, it may also offer some advantages in that the disposal is less likely to directly impact the coal removal operation. There is less pit congestion, less potential of creating spoil bank instability, and generally less stringent scheduling requirements. For these reasons, spoil bank disposal may often be preferred to pit-bottom disposal.

Mixing with Overburden

Waste disposal operations can be adapted to allow mixing of the waste and overburden. This can be accomplished readily in contour strip mines where haulback methods are used and in some Western mines where overburden is handled by truck. However, in many strip mines, mixing waste and overburden or sandwiching waste between layers of overburden may require too much additional handling of materials as well as added constraints on the dragline or shovel operation. Thus, in most mines this type of operation is not expected to be practical.

Overall Disposal System Implementation

There are many possible disposal system configurations depending upon the type of waste (filtered waste admixed with fly ash or treated), distance between the power plant and mine, and the type of placement. In general, though, the distance between the mine and power plant is the overriding factor which dictates the amount of handling and the types of transfer facilities required.

For onsite (mine-mouth) disposal operations, truck transport of wastes would probably be preferred. In many cases it would be advantageous for the fly ash/filter cake mixing system or waste treatment operation to be tied directly to the truck transport system to minimize double handling of material and minimal storage capacity for the wastes. For offsite mine disposal where the mine is more than a few miles from the power plant, rail haul of the wastes is a practical and economical alternative. Either the same train used to carry the coal or a dedicated smaller train can be used to carry the waste to the mine. If the coal train is used or if the distance between the power plant and the mine is such that the turn-around time on a dedicated train is long, then waste transfer/storage areas at both the mine and the power plant would probably be required.

2.2.4 Underground Mine Disposal

Underground mine disposal of FGC wastes is not currently practiced. However, there have been a number of studies evaluating the potential for underground mine disposal including work by Radian [75] for the U.S. Bureau of Mines, a study by Arthur D. Little [29] for the U.S. EPA (IERL), and a study by Michael Baker Jr., Inc. [76] for the U.S. EPA (MERL). These indicate that such disposal operations are technically feasible and can be economically viable as well as environmentally acceptable. In fact, underground mine disposal may offer potential benefits in terms of subsidence control, fire prevention, and prevention of acid mine drainage.

Description of Mining Operations

There are two basic underground coal mining methods: room and pillar, and longwall. Underground coal mines are also often classified as slope, drift, or shaft mines, depending upon the method of access rather than the mining method used.

Room and pillar mining involves removal of the coal in "rooms" leaving "pillars" to support the roof. Room and pillar coal extraction can be "conventional" wherein the coal is extracted in a series of discrete steps (undercutting the coal, drilling, blasting, loading, and shuttle car haulage to main haulage belts or rails) or "continuous" where continuous mining machine cuts the coal, loads and delivers it to shuttle cars (which really makes the system only semi-continuous) or to conveyor belts for removal from the mine. In most room and pillar systems another important step is to place roof bolts for supports as the mining proceeds.

If the pillars are not robbed, the coal extraction is on the order of 50%. If geologic and roof conditions permit and if surface caving can be allowed, the pillars can be robbed (removed) as one retreats back to the access opening, which can increase extraction to 70-80%. Complete extraction through pillar robbing is not technically feasible.

Longwall mining systems rely on the controlled caving of the roof. The system consists of a coal cutting machine, chain conveyor system, and hydraulic movable roof support. The operation of longwall coal systems is more nearly continuous (when they operate successfully) than room and pillar mining, with coal cutting, removal, and prop advance going on steadily. When the props are advanced, the unsupported roof caves and leaves what is known as gob area.

Most U.S. coal mines using longwall techniques also produce coal by room and pillar methods; hence, coal production from any mine is rarely all from the longwall mining operation itself. Longwall mining methods (including shortwall mining) cannot be used in all underground coal mines in the United States. Application of longwall operations are limited to areas where the surface above can be disturbed and where the coal to be mined occurs in configurations amenable to the longwall layout.

FGC Waste Placement

In general, old, inactive underground coal mines offer less promise than active underground coal mines for FGC waste disposal. Abandoned mines are often caved and filled with groundwater of unknown flow patterns caused by the hydrogeologic changes created by mining. The voids are difficult to find because of prior roof collapse as pillars deteriorate and fail. Even the initial open cavities prior to roof collapse are difficult to delineate, as underground mining plans for abandoned mines are generally not available. Only in a few isolated instances, where mine conditions are fairly well defined and where disposal of FGC wastes can be justified as a method for limiting acid mine drainage formation and/or to prevent further surface subsidence damage does disposal in abandoned mines appear promising.

Active underground coal mines (disposal in mined-out sections of active mines), show considerably more technical promise. However, waste placement would still add complication and additional maneuvering to the already difficult working conditions. Also, many of the underground mines utilizing a combination of both conventional room-and-pillar mining with pillar robbing and/or longwall mining may limit the available capacity for waste disposal or may require more than one disposal placement technique.

There are basically three approaches that can be or have been employed: pneumatic backfilling, hydraulic backfilling (or flushing), and mechanical stowing. These have been demonstrated or practiced in both the United States and Europe for disposal of mine tailings or placement of fill materials in underground mines.

Pneumatic Backfilling

Pneumatic backfilling simply involves blowing the material into the mine void through a pipeline either from the surface, which enters the void through boreholes in the roof, or from an underground station mounted at the entrance to a voided area. Practically speaking, pneumatic backfilling would have to be done by blind injection, that is, without the aid of men underground during the backfill operation to direct the flow of material and control the distribution.

Pneumatic backfilling has been successfully used for the disposal of fly ash in coal mines, indicating that it may be feasible for use with FGC wastes. In fact, pneumatic backfilling (stowing) may be the only feasible method for waste disposal in conjunction with longwall mining operations. The obvious limitation with regard to FGC waste disposal, though, is that the material must be dry and free-flowing. Because of the limited experience with pneumatic stowing and the limitations it places on the form of the waste material, it is not anticipated that pneumatic stowing will gain widespread use for waste disposal.

Hydraulic Backfilling

There has been considerably more experience with hydraulic backfilling both in the United States and Europe than with pneumatic stowing. This method has been successfully used to return coarse mine tailings from both coal and metal mines to mine voids.

In contrast to pneumatic backfilling, hydraulic backfilling can be practically accomplished either by controlled or blind injection. The distribution of material achieved depends upon the pressure head at the pipeline, the solids content of the slurry, the arrangement of the discharge piping, and the characteristics of the mine void (mine layout, coal bed slope, etc.). In some cases where there is sufficient slope of the area being filled, it may not be necessary to install bulkheads to block out the disposal area to prevent flowing of the material to the active areas of the mine. However, in most operations utilizing mined-out portions of an active mine it would have to be assumed that the bulkheading would be required, particularly where the waste is introduced through the boreholes in the mine roof.

In hydraulic backfilling of FGC wastes the solids content of the waste slurry will vary with the type of waste material. In most cases it is reasonable to assume that a slurry containing a minimum of 25-30% solids could be piped into the mine void. With this slurry concentration, settling in the mine void can be expected, and provisions may need to be made to pump out water/liquor runoff. If dry wastes are slurried for hydraulic backfilling (or thickened waste is diluted), then the collected drainage could be recycled for slurrying the wastes.

A wide variety of wastes can be handled, ranging from simple, untreated calcium-sulfur solids generated from the removal of SO_2 to mixtures of ash and calcium-sulfur wastes or even treated slurried material. Treated material may offer some advantages in that once stored in the mine it will cure and harden, resulting in a relatively hard, monolithic mass which would be resistent to flow and may also provide a small amount of subsidence control.

Mechanical Stowing

Mechanical stowing of wastes can be accomplished in active mines using existing transport/conveyance equipment or equipment that can be readily adapted for use in the mine. Such operations would generally not be economically attractive in comparison to hydraulic backfilling; however, it may be appropriate for use in certain types of mines such as underground limestone mines where there is ready access to mining areas. In fact, in limestone mines it may be possible to place wastes via truckload delivery, since these mines have large, open rooms accessible from the surface.

Overall System Implementation

Hydraulic backfilling of underground mines is most easily accomplished at mine-mouth power plants or where the distance between the power plant and mine is a few miles or less. In such cases, wastes can be piped directly to the mine and pumped down the mine borehole. Piping of wastes for long distances, though, can be a problem, particularly if stabilized wastes are to be used. Thus, this may involve dewatering of the wastes, transport and reslurrying prior to disposal, all of which would require considerable rehandling and extra cost.

Where the power plant is located adjacent to the mine, the wastes from the scrubber system can be first thickened to 20-35% solids and then pumped to the mine and down the boreholes. At the mine, drilling of boreholes and construction of bulkheads across mine voids would be an ongoing operation to provide new sites for the waste disposal. An interim storage tank may also be required for the wastes to handle periods of disposal system interruptions. As the waste materials settle, it will probably be necessary to also pump out the decanted liquor and return this to the scrubber system.

2.3 Ocean Disposal

2.3.1 Overview

Ocean disposal of FGC wastes is not practiced today. However, if it could be practiced under environmentally satisfactory conditions, it could represent an important option, particularly in the Northeast where land for disposal is limited. For this and other reasons, EPA has been studying the disposal of FGC wastes in the ocean [29]. At present, regulation of dispersed ocean dumping of treated and untreated FGC waste falls under the Marine Protection Research and Sanctuaries Act and is administered by the Environmental Protection Agency. The dumping would be required to occur at EPA prescribed dumpsites under the following conditions:

- Mercury, cadmium content of the dumped materials would be no higher than 50% above that of background sediments at the dumpsite,
- Concentrates of the dumped material in the water column four hours after release would not exceed 1% of the 96-hour LC_{50} of the material to local sensitive species, and
- No feasible alternatives to ocean disposal are available.

Stabilized, brick-like FGC waste may potentially be used to create artificial fishing reefs with EPA concurrence. Artificial fishing reefs are not subject to ocean disposal criteria but FGC waste disposal may be a special case. At any rate, the issue has not been finally decided upon. While ocean disposal of FGC waste is an option that is perhaps available to throwaway system users with economic access to the ocean, new ocean disposal initiatives are now discouraged by the regulatory agencies. If current studies on ocean disposal of FGC wastes indicate that environmentally sound disposal is feasible, then the regulatory posture could change.

There are two types of ocean environments for FGC waste disposal:

- Shallow ocean (on the continental shelf), and
- Deep ocean (off shelf).

Each area has a different ecology and may therefore be subject to different considerations when evaluating environmental impact. That subject is discussed further in Section 4.3 of this volume.

2.3.2 Disposal Technology

Technology for disposal of FGC wastes in the ocean can be broadly subdivided into:

- Transportation, and
- Surveillance and monitoring.

The former is discussed here, the latter in Section 5.3.2 of this volume.

Methods for ocean dumping are determined principally by the nature and form of the waste to be disposed of, and the disposal site in relation to the site of origin. Consequently, the nature and form of a new waste, unsuitable for an existing transport system might have to be changed to make it acceptable for use with the given transport system.

There are currently a number of viable techniques for transporting waste mixtures to offshore disposal sites. Existing practical technologies allow either (a) controlled dispersal of the sludge over a great expanse of water or a sudden total dump; or (b) a continuous pipeline discharge of the sludge. These techniques would fall into the following categories:

- Self-propelled hopper ship with throttled discharged disposal or with a sudden dump capability,
- Tow-barge transportation and controlled dispersal over a great expanse of water or a sudden total bottom dump, and
- Submarine pipeline transportation and dispersal at a preselected offshore disposal site.

All these approaches are technically feasible systems which have been utilized on a full scale for other wastes. Selection among them depends upon both the characteristics of the waste to be dumped and any environmental conditions and/or constraints that might exist.

Pipeline Transport

For pumpable wastes, this method is mechanically simple. Using an ocean outfall, FGC waste may be piped many miles to be discharged (usually) through a section of diffuser conduit several feet above the bottom. Typical operation is fairly simple, consisting of monitoring and maintenance of the pump, pipeline, and diffuser. Depending on operation of the solids removal process and resulting effluent concentration, active regulation of pump rate may be necessary. When waste production is small enough to permit intermittent operation, the outfall may require flushing with fresh or reclaimed water after each discharge period to prevent sedimentation and possible clogging of the diffuser. Underwater pipeline construction can be done by bottom pull, floating pipe, and lay barge pipeline positioning. Lay barge techniques have been used to install underwater pipelines of 30-inch diameter for distances over 100 miles. In practice, for design purposes, physical model experiments may be required to determine critical velocities or appropriate dilutions of the particular sludge.

The costs of offshore pipelines generally vary with length of the line, depth, pipe size, ocean terrain, and materials to be transported. The greatest single cost factor in such pipelines is the installation cost, which generally runs more than 50% of the total investment. Maintenance is usually the biggest cost factor in the operation of such pipelines.

Surface Craft Transport

The generalized alternative to pipelines lies in carriage of the material in batches by surface craft to a selected dumpsite. A prerequisite for surface release is that the material have a density greater than water—or in the case of inert or harmless materials, that it be soluble with a rapid natural rate of dispersion. The vehicle, i.e., the container for this transport of the material, may be a barge or a self-propelled craft. The material itself may be in any one of many forms. In general, economics demand that the material be carried in as concentrated form as possible and that the transport of large tonnages of water be avoided.

Surface craft adequate for offshore disposal purposes exist and are in use today. Self-propelled hopper-type ships are also currently in use for waste disposal. The basic configuration of these types of vessels would resemble the hopper-type dredges owned and operated by the U.S. Army Corps of Engineers. The capacity of these hopper dredges varies from a low of 720 cubic yards to a high of 8,277 cubic yards; however, European dredges are even larger. Better (specially designed) equipment is feasible. Newer designs may be required to control the rate of release of sludge particularly where high dilution factors are required. However, under almost all conditions, disposal of slurried FGC waste would be economically impractical. The cost of transporting FGC slurries would be unattractive, and reslurry of dry or thickened sludge on board large disposal vessels could require impractically large pumping capacities. A major cost consideration for surface craft involves the necessity to employ two or three crew shifts if the dumpsite is located outside a round trip range which can be covered in eight hours or less.

Surface craft can practice one of the following types of dumping:

- Direct release under gravity through the bottom of cargo craft.
- In recent years a new dump concept has appeared in the form of the clam-shell barge. A hopper barge is split along a vertical longitudinal plane and the two symmetrical halves are hinged at deck level. Buoyancy compartments are arranged so that when the barge is loaded, control exists to open the joint; when the hopper is empty, controls can snap the two halves shut.
- In cases where the material is unsuitable or where operating conditions mitigate against the use of large hull openings and joints, the material must be lifted over the side of the craft and dumped into the sea. If a deck barge with bulwarks is used, the material can be shoved overboard through an opening in the bulwarks by some form of small bulldozer. From a hopper, methods as crude as the use of a crane and bucket are employed. The latter requires expenditure of considerable power, use of manpower, and is unsuitable in any sort of seaway. Less power and less attendance is required for pumping the material overboard, but in this case the material must be liquefied to the extent that a slurry is formed.

Scheduling of ocean disposal can also affect the direction in which waste materials are being transported, and, hence, environmental impacts. If the ocean disposal occurs only on the ebb or flood tide, dispersion of the waste is somewhat restricted to one direction. Generally, one would try to maximize seaward dispersion.

To limit the impacts of sludge disposal, the location of dumping has to be controlled. There are two aspects to such control. The first deals with navigational accuracy available (or the ability to find any specified dumpsite with precision). The second deals with policing the operation to make certain that dumping takes place at the specified location (within the accuracy limits of the available navigation systems).

Adequate means of navigation are currently available to allow fixing the location of any particular dump to well within one mile with visual control and within 0.8 to 5 km (0.5 to 3.0 miles) using navigation aids [29].

2.3.3 Current Studies

At present, the major studies under EPA sponsorship or participation relating to the ocean disposal of FGD wastes are:

a. The Arthur D. Little/New England Aquarium study [29, 31] for EPA on the technical, economic and environmental feasibility of the ocean disposal of stabilized and unstabilized FGC wastes. This study includes both laboratory and small-scale field testing relating to impact issues.

b. The State University of New York (SUNY) [32] with funding provided from Power Authority of the State of New York, New York ERDA, DOE, EPRI, and EPA, is studying the use of stabilized brick-like FGC wastes (using IU Conversion Systems process) to create artificial reefs for marine habitats. This study is expected to continue for 2 to 5 years.

The preliminary conclusions from the Arthur D. Little/New England Aquarium study for the EPA are [31]:

- A case-by-case approach to the analysis of the environmental feasibility of ocean disposal of specific FGC sludges is needed. The emphasis in each analysis should focus on the type of sludge and the disposal site environmental conditions.

- Unless further work contradicts observed and anticipated benthic sedimentation impacts, including mudflows, it would appear that the disposal of untreated or treated FGC sludges with soil-like physical properties by bottom-dump barge or outfall on the continental shelf is environmentally unacceptable.
- The problems of disposal of sulfite-rich FGC sludges, both on and off the continental shelf, appear to be much greater than those associated with other FGC materials. There appear to be special grounds for concern over the potential for oxygen depletion in the vicinity of sulfite-rich sludge masses. However, sulfite toxicity may be a relatively minor problem because of the significant rate of the oxidation reaction.
- Disposal options which still appear promising and are recommended for further research include:
  - dispersed disposal of untreated, sulfate-rich FGC sludges on the continental shelf;
  - concentrated disposal of treated, brick-like FGC sludge on the continental shelf;
  - dispersed disposal of treated, brick-like FGC sludge on the continental shelf;
  - dispersed disposal of untreated, sulfate-rich FGC sludges in the deep ocean; and
  - concentrated disposal of both untreated and treated sulfate-rich FGC sludges in the deep ocean.

2.4 Disposal Options vs. Potential Environmental Impact Issues

2.4.1 Overview

Environmental impact issues associated with FGC waste disposal are determined by a mix of four factors:

- Waste characteristics,
- Disposal mode,
- Site, and
- Control measures employed.

The range of options in terms of control measures is sufficiently broad that on balance, technology exists for environmental sound disposal of FGC wastes.

The environmental impact issues requiring consideration in handling and disposal of FGC wastes are:

- Land-related,
- Water-related,
- Air-related, and
- Biological impacts both in the site and adjacent areas and consequential effects.

Table 2.1 discussed earlier listed all potential disposal options for FGC wastes. Table 2.12 lists the issues and mechanisms or factors causing the impacts. Potential impact issues are highly site- and system-specific. With that understanding, Table 2.13 illustrates the major types of impact issues associated with various disposal options. As the matrix illustrates, the range of waste types and possible disposal conditions is sufficiently broad to eliminate the potential for "generally significant" issues to be associated with any of the disposal options. Further, site-specific application of appropriate control technology can be employed to mitigate adverse impacts. In other words, issues of potential significance in FGD waste disposal can best be defined in terms of specific waste types, disposal practices, and disposal environments. The significance of many potential impact issues needs to be better quantified by additional field-scale operating experience (and environmental monitoring) with FGC waste

Table 2.12

Potential FGC Waste Disposal Impact Issues

Impact Area	Impact Issues	Mechanisms/Factors
Air Quality	Fugitive Particulate Emissions	Handling, Transport, Erosion
	Gaseous Emissions (e.g., H_2S, SO_2)	Biologic Interactions, Acid Leaching
Water Quality	Groundwater Contamination	Leaching
	Surface Water Contamination	Runoff, Overflows, Leaching
Land Use	Physical Disruption	Stability
	Land Reclamation/Reuse	Disposal Mode, Stability
Biota	Habitat Displacement	Disposal Mode
	Bioaccumulation/Transfer	Water Quality, Direct Uptake

Table 2.13

Disposal Options Versus Potential Environmental Impact Issues for FGC Wastes

	Potential Environmental Impact Issues				
Disposal Options	Land Use	Surface Water Quality	Groundwater Quality	Air Quality	Biological Impact
Wet Ponding	2	2*	2*	3	2*
Dry Disposal	2	2*	2*	2*	2*
Surface Mine Disposal	2	2*	2*	2*	2*
Underground Mine Disposal	3	3	2*	3	2*
Shallow Ocean Dumping	3	2*	3	3	2*
Deep Ocean Dumping	3	2*	3	3	2*

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* Significance highly uncertain due to data gaps.

Key: 1 = Issue of potential general significance for all FGC wastes at all disposal sites.
2 = Issue of potential significance for specific types of FGC wastes and/or specific disposal sites.
3 = Issue of minor or no potential significance.

Source: Arthur D. Little, Inc.

disposal. As indicated in the matrix, this is particularly needed for defining potential issues in the categories of water quality and biological impacts.

The remainder of this section provides introductory information on the general mechanisms of potential environmental impact in each of the issue categories shown in Table 2.13. The section concludes with a discussion of the means by which broadly defined issues become specific and subject to more thorough quantitative and qualitative evaluation for various FGC waste types, disposal practices, and disposal environments. Section 4.0 presents results of such evaluations reported as of late 1978.

2.4.2 Mechanisms of Environmental Impact for FGC Waste Disposal

The chemical and physical properties of FGC wastes (discussed in detail in Volume 3 of this report) create several mechanisms of potential impact in each environmental medium (air, water, etc.). These mechanisms are discussed below under headings corresponding to the various impact media. This discussion is intended to provide perspective as a precursor to subsequent sections dealing with specific research programs and their findings.

2.4.2.1 Land-Related Mechanisms of Impact

This section is divided into two parts, focusing respectively on the technical (i.e., physical) nature and the public-policy implications of the impact mechanisms associated with the use of land for FGC waste disposal.

2.4.2.1.1 Technical Nature of Land-Related Impact Mechanisms

The stability of FGC wastes after disposal is a major influcence on the impact potential of the various disposal options. This is because physical instability can have adverse impacts on disposal site reuse, and chemical instability can be a mechanism of contaminant mobilization in the disposal environment.

Physical instability is a potential problem for all FGC wastes, including treated wastes. As discussed in Section 2.2, significant data gaps exist in engineering information. Three processes that have important effects on the physical stability of FGC waste material are consolidation, subsidence, and liquefaction. Secondary considerations (but also important) are durability and permeability.

- Consolidation is the change in volume of the material caused by flow of liquid out of pores between solid particles under a hydraulic gradient created by the weight of the material itself or by the application of external loads. In fine-grained materials such volume change and consequent surface settlement may require months or years to reach completion.
- Subsidence (surface settlement) may be caused by consolidation of waste materials or by loss of basement support (as might happen in a mine disposal situation). Subsidence may occur episodically from loss of basement support, but usually occurs over relatively long time periods (months to years).

This is in contrast to liquefaction, which can take place suddenly and without warning.

- Liquefaction can occur in a saturated waste which, like fine-grained, relatively cohesionless soils, under loading cannot drain freely; the pore water pressures may increase until the intergranular stresses are eliminated. The shear resistance is, therefore, nullified, and the material flows like a liquid. Such loading may be caused by the vibration of heavy machinery, including bulldozers, blasting, pile drivers, or earthquakes.

A mass of liquefied FGC wastes would flow very rapidly, possibly at speeds of tens of feet per second near a failing wastes deposit. Speed of flow would approach that of water at very low sludge (or mix) solids contents. Speed would decrease with distance from the failing mass and with increasing solids content.

Vibrations can also cause excessive subsidence in fine-grained cohesionless materials (which includes most FGC waste). The frequency of the vibration is a key determinant in the degree of subsidence. If the vibration frequency approaches the critical frequency, subsidence may be 20 to 40 times as great as that caused by an equivalent static load. The greatest amounts of consolidation occur from frequencies in the 10 to 30 Hz impulses per minute range. The problems of susceptibility to vibrations are limited by two circumstances. The influence of a point source of vibrations diminishes geometrically with distance. In addition, properly compacted materials (e.g., compacted with vibratory rollers at proper moisture content) are not vulnerable to subsequent vibrations.

The durability of the materials within a filled area is critical as it relates to the maintenance of structural integrity. Freezing has been observed to cause fracturing of sludges and subsequent subsidence due to loss of compressive strength. Freeze-thaw cycles could have several effects. Fixation reactions could be retarded, disrupted, or destroyed by an episode of freezing soon after mixing and placement. Freezing could produce cracks in the near surface layers of a waste deposit (frost polygon behavior). Cracks in the wastes deposit could yield greater mass permeability and infiltration rate even though waste blocks between cracks had been compressed and even dewatered.

Durability is a waste- and site-specific property which can best be determined in the field over a length of years through many lab analyses of aged field samples. Mass permeability and infiltration are important in that increases and decreases in the water content of unsaturated materials will alter their properties and thereby alter the stability of the materials. Thus, the grading of a filled area (and hence, the extent of infiltration of precipitation) may be critical to its stability. Increased infiltration could lead to saturation of wastes previously unsaturated and could cause generation of significant porewater pressures. Saturation would increase the weight of the wastes, and porewater pressure generation would decrease effective stress, thus decreasing the strength of the wastes deposit. Both factors tend to lead to sliding/slumping. This would be most likely to occur with wastes of highest permeability in an unsaturated condition, but it could occur in any FGC waste deposit.

There are various processes which can be used to alter both index and mechanical properties of FGC wastes. (See Volume 3.) Addition of chemicals such as lime, silicates, and aluminates can cause a pozzolanic reaction to occur in fine FGC wastes in the presence of water. Like concrete, these pozzolanic materials require a curing period. Other commercial processes have been developed which produce soil-like rather than concrete-like substances from FGC wastes. The pozzolanic materials, when properly cured, can be stronger than underlying soils. Soil-like treated wastes are generally denser, stronger, less compressible, and less permeable than many untreated FGC wastes. Thus, the placement of treated waste is not as environmentally important as that of untreated waste from a stability standpoint.

Data is lacking on "lifetimes" of fixed wastes. Chemical species created during fixation may propagate in the field during completion of initiated reactions; they may be altered or they may be removed. If the bonding between particles, which was created during fixation, is weakened or eliminated, instability may result. This is a complex question, e.g., Portland cement concrete increases in hardness, stiffness, and strength for years after mixing and placement if weather and other factors (e.g., sulfates in the groundwater) do not cause deterioration.

Physical factors such as compaction effects also may alter with time. If the wastes are saturated with low solids content, consolidation may occur with significant increase in solids content, stiffness, and strength; this may be significant for thickener underflow consistencies. Increase in density (and consequent increase in strength) created by compaction should not disappear, but long-term saturation may dissipate suction effects (and the increase in strength due to suction) created during compaction. Dissipation of suction effects would have most effect near the surface of a waste deposit because, at depth, overburden pressures continue to create interparticle stresses equal to the interparticle stresses previously created by suction in the porewater.

Co-disposal of mixtures of ash and sludge (see Section 8.2.2) exhibits impact potentials different than those of independent disposal. It may be easier to handle the sludge-ash mix than to handle (transport, place, compact, etc.) sludge or ash alone. The potential air emission problems of dry ash handling would be eliminated. Fill construction would be easier using one material rather than two at the same site. The mix of ash and sludge should be less compressible and stronger than sludge alone and less subject to erosion than ash alone. The mix of ash and sludge may be self-hardening or it may require less fixative in a mixed fill than the materials would in separate fills. A possible disadvantage could be an increase in permeability (ash-sludge mix vs. sludge alone) with potential for more infiltration and leaching.

2.4.2.1.2 Land Use Policy Implications of FGC Disposal

Land use impact issues, viewed from the "Public Policy" standpoint, are focused on three aspects of FGC waste land disposal options:

- Site location,
- Post-closure land use of a disposal site, and
- Impact potential of disposal on adjacent lands.

As the above list indicates, the significance of these issues is highly site specific. However, they are dealt with in the generic sense in the discussion below.

Site Location

The mechanism of impact on public policy in this instance is similar for FGC wastes and most, if not all, other solid wastes. At the local level, fulfilling land requirements for solid waste disposal has become problematic in many areas; either because of a lack of suitable available land, and/or because of local public resistance to sites chosen for waste disposal. This situation is reflected in regulations being developed at both the federal and state levels. A recent draft of guidelines, generated under the Resource Conservation and Recovery Act (RCRA) for the development of state solid waste management programs [33] for non-hazardous wastes, requires that state plans include provisions for adequate disposal facilities as well as identifying or obtaining the plan implementation authority. Similar wording can be found in some existing state solid waste management regulations for approval of county or municipal solid waste programs. (See Section 3 of this volume.) It is emphasized that problems in initial site location, when they exist, would be location-specific rather than generic to FGC waste types or disposal practices.

The potential designation of FGC wastes as hazardous or "special" under RCRA could exacerbate problems with site location due to public sentiment. Again, these would be location-specific issues. Some current state regulatory programs address this issue. Under existing California regulation, FGC wastes would apparently be included among "Group I" wastes requiring disposal in sites that provide maximum protection from leaching and surface runoff [34]. Oregon's regulations illustrate a different issue; in that state, hazardous waste facilities must be state owned.

Waste land areas, with irregular topography (for ease of containment and a source of cover soil) and highly impervious subsoils, would be ideal sites for FGC waste disposal. Valuable, flat or uniformly sloping areas with highly pervious soils and scarce, pure (thus valuable) groundwater would be poor locations for disposal sites.

The above discussion assumes that open land would have to be found for a disposal site. Disposal of FGC wastes in operating surface or underground mines or at abandoned mine sites would not require "new" land. The regulation of non-coal waste disposal at active mine sites is, (as of early 1979), still under consideration by the Office of Surface Mining due to the Surface Mining Control and Reclamation Act. (See Section 3.) The use of FGC wastes in abandoned mine reclamation is discussed further below.

Post-Closure Land Use of Disposal Sites

The present regulatory climate, defined by existing and emerging regulations, establish post-closure land use of disposal sites as an impact issue that must be considered:

- Under Federal standards for hazardous waste disposal facilities [3], land at a closed site must be "amenable to some productive use." Where wastes remain at a disposal site, certain land uses are precluded (residential and agricultural, for example).
- Some state solid waste programs already include bonding requirements for either solid waste or hazardous waste site operations to cover site reclamation and even "perpetual care" of sites where considered necessary. (Examples include: Kansas, 1978; and Tennessee draft regulations, 1978.) The Kansas Solid Waste Management Act even includes requirements for a site post-closure land use plan to accompany the permit application for non-hazardous wastes. Restrictive covenants can be established, where deemed necessary, to limit land use or describe mitigating requirements for closed disposal sites.
- The Surface Mining Reclamation and Control Act requires reclamation of mined land, in most situations,to be capable of supporting its pre-mining uses. It also establishes a fund, for use by states, for abandoned mine reclamation.

Post-closure land use would tend to be limited by the nature of the loads created or by the sensitive nature of the structures or facilities built on the waste fill. For example, placement of some sort of fill in a uniform layer over the entire waste deposit should be feasible, but imposition of concentrated loads (e.g., footings in a building) may cause bearing failure with rapid plunging of the loaded element into the wastes. Vibratory loads as from machinery foundations could have adverse effects on unfixed wastes. The rate of application of load also is extremely important--loads applied slowly may allow consolidation of the wastes during loading, yielding higher strength than for material loaded rapidly. Rapid application of load increases shearing stresses and may decrease shearing resistance if the structure of the wastes is disturbed (collapse or remolding).

The nature of the supported use also is important. A park built on cover soil over FGC wastes would not be affected seriously by wastes settlement. A low, flexible structure like a warehouse would exert low loads and could tolerate greater total and differential settlements than could a structure like a boiler-turbine-generator complex.

The various disposal options for FGC wastes present somewhat different potential impact issues relevant to post-closure land use. These issues are discussed separately below for the various land disposal options, noting that this is a general, not site-specific discussion.

Dewatered Impoundments and Dry Disposal

For a discussion of post-closure land use impacts, it is assumed that the final closure procedure for these options would include some type of soil cover once drying or setting is complete. In addition to the overall stability of the closed disposal area (discussed in 2.4.2.1.1 above), suitability for post-closure uses could be determined by the revegetation which may be accomplished, and the extent to which migration of waste-related contaminants could occur. The latter issue includes the degree to which the underlying material could reduce vegetation growth rates and/or result in significant vegetative uptake of trace elements. Thus, the attentuation capacity of surface and underlying materials, climate regime of the disposal site, as well as the physical and chemical characteristics of the disposed material are important contributors to determination of site reuse capabilities. Another question concerning reuse potential is whether or not there are ameliorative properties of FGC wastes (or waste components) for certain soil types that would justify this type of land application. A corollary question is whether or not a final soil cover would have to be used to eliminate some trace contaminant impact potential if food-chain vegetation were to be grown on a waste/soil mixture.

Mine Disposal

The use of FGC waste in the reclamation of surface or underground mines would appear to be a potentially satisfactory disposal practice, especially where used to limit acid mine drainage. However, disposal in surface mines, while feasible, is space limited (and hence, time limited) due to the reclamation requirements of the Surface Mining Control and Reclamation Act. Disposal in abandoned underground mines appears likely to be limited in many cases by abandoned mine conditions.

Long-term land use impact issues associated with FGC waste disposal in surface mines are similar to those associated with landfills, although the significance of impact may vary due to variations in the depth of placement of disposal material and disposal techniques. Given SMCRA reclamation requirements, it is important to address the degree to which the physical or chemical characteristics of the waste material could affect post mining reclamation efforts (e.g., the stability and contaminant migration issues discussed above). The potential for migration of contaminants into surface soils would be an issue of greatest concern for surface mines located in areas of prime farmland.

The existence of an underground mine would appear to be a more significant issue in limiting post mining surface land use in most cases than would the additional disposal of FGC waste in the mine. Two notable exceptions must be considered: (1) the long-term potential (if any) for SO_2 emissions in acid mine areas; and (2) future surface stability.

2.4.2.1.3 Impact Potential of Disposal on Adjacent Land

Mechanisms of offsite land use impacts are essentially similar for all land-based FGC waste disposal options. Uses of adjacent land could be restricted by access or geometry limitations (e.g., difficulty in building access roads across waste deposits) or by consideration of possible failure of wastes retention structure, or by pollution effects (losing the use of groundwater through pollution by leachate from FGC wastes). The impact mechanisms of principal concern are the potentials for leachate to enter groundwater systems and for contaminants to enter surface water. These issues are both discussed in the following section. These are only indirectly land use issues--insofar as water issues do have an impact on users (well water contamination, for example). Variations in the significance of impact would occur for different waste types, site-specific climatic and hydrogeologic conditions, and disposal techniques.

The case of very large impoundments built by construction of a dam may pose an additional issue. This would include the extent to which a valley watershed serves downstream users and the degree to which the disposal site would affect long-term alterations in surface water conditions (i.e., quantities and quality).

It is also possible that the nature of adjacent land use could affect the suitability of some locations for use as FGC waste disposal sites. For example, if a prospective FGC waste disposal site was immediately downgradient of a mining or logging area, removal of vegetation on the adjacent area could affect erosion rates (and stability of the downgradient FGC waste site.

2.4.2.2 Water-Related Impact Mechanisms

For many disposal options, the potential for water contamination can be among the more serious environmental impact issues pertaining to the disposal of FGC wastes. As is true for other potential impact mechanisms, the potential for water contamination as a result of FGC waste disposal is highly site specific and sometimes waste specific: control measures required at one site may be unnecessary at another; practices useful in controlling or preventing water contamination at one site may not be efficacious at others. Understanding of the mechanisms of surface and/or groundwater contamination by FGC waste disposal has been limited by the lack of field-scale disposal and monitoring experience. This constraint is still effective today, but increasing requirements for the protection of water resources have led to a substantial recent expansion in research efforts. The recent announcement of a large EPA Program [21] and EPRI Program [15] are expected to fill this gap. This is discussed in Sections 4.2, 4.3 and 4.4 below.

Table 2.14, outlining potential water impact issues, indicates that some potential for water contamination exists for ocean disposal and all land-based disposal options, including transportation. However, as indicated, the probablility of water contamination during transport is quite low, and no research or regulation of transport of FGC wastes, with specific emphasis on water, is anticipated.

Table 2.14

Relative Potential for Water-Related Impacts from Different FGC Waste Disposal Options

			Disposal Option			
Waste Type	Transportation	Ponding	Dry Disposal	Surface Mine Disposal	Underground Mine Disposal	Ocean Disposal
1 Ash	Low	High	High to Moderate	High to Moderate	High to Moderate	High
2. Sulfite Rock	Low	High	"	"	"	"
3. Mixed Sulfite/Sulfate	Low	High	"	"	"	"
4. Sulfate Rock	Low	High	Moderate	"	"	Moderate
5. Stratified Waste	Low	Moderate or NA	Moderate	"	"	Moderate
6. Sulfur	Low	NA	Low to Moderate	Low to Moderate	"	Moderate

NA = Not applicable

* Actual adverse impact potential is mitigated for all options by available control technology and regulatory requirements for the protection of water quality.

It is important to remember that this table and discussion are on a relative basis among disposal options. The potential for negative impact is compared on a disposal option vs. waste type basis. When considering the actual characteristics of a disposal operation, that is, disposal option x waste x site x control measures implemented, it may be feasible to reduce or eliminate the actual impact even for option x waste combinations which have a high generic probability of impact.

Unstabilized sulfite-rich sludges are identified as having a high generic potential for water impact for all disposal options except dry disposal, which is not considered feasible for such a sludge. Features of unstabilized sulfite-rich sludges which lead to their relatively high generic impact potential are:

(a) Their high water content which, through a variety of mechanisms including physical instability, increases the likelihood of interaction between the waste and ambient water [35,36], [37]; and

(b) The relatively high COD of sulfite-rich sludges which can lead to initial depletion of dissolved oxygen in ambient water whenever it interacts with the waste in an agitated medium [38,39].

Other unstabilized sludge has only slightly lower generic potential for water impacts than sulfite-rich sludge. Unstabilized sludges by definition have poorer physical stability, and disposal site management for control of runoff and leachate is consequently more difficult. Such practices, as grading to promote runoff and eliminate standing water, thus reducing leachate generating, are reportedly infeasible for most untreated FGC sludge [35,36]. Leachates from untreated sludges can exhibit concentrations of various parameters, including TDS, SO_4, Chloride, As, Se, and Hg, in excess of EPA drinking water standards, defining leaching as an impact mechanism of considerable interest [39,40].

Several investigators have concluded that stabilization of FGD sludges by addition of such pozzolanic substances as fly ash, fly ash and lime, or Calcilox®, will reduce permeability and leachate concentrations of TDS and certain major dissolved constituents [35,36].

Thus, stabilization affects the probability of water contamination as a result of disposal of FGC wastes. However, some studies report that not all parameters are reduced in leachate from stabilized FGC materials; some exhibited increased concentrations [41]. The magnitude of the reduction in mass of pollutants released, estimated by one report at 1/20 of the pollutant potential of untreated sludge [9] is not so great as to entirely obviate the potential for water contamination. Furthermore, as is true for other proposed control measures, evidence of the effect of stabilization [9] on water impact in field tests is unavailable at this time. Accordingly, the potential for water contamination by disposal of stabilized sludges is still considered a realistic mechanism of impact.

Fly ash disposal also presents a significant potential for water contamination because of the relatively high concentrations of trace elements sometime found in fly ash leachate. Theis [42] reported cadmium, lead, and arsenic concentrations in excess (4 to 25X) of EPA Interim Primary Drinking Water Standards in fly ash and leachate.

Ocean disposal, ponding, and disposal in the surface mine pit present high generic potential for water contamination because in each case the waste is likely to be in intimate contact with surface water and/or groundwater in the saturated zone. The maintenance of water head in a pond causes percolation into the soil and eventually can result in elevation of the water table beneath the pond. Lining the pond is a way to retard or prevent this sequence, but available liners are generally not perfectly impermeable and are subject to leaking [43,44].

FGC waste disposal in the working pit of a surface mine followed by covering with overburden creates a mechanism of potential groundwater impact because the pit floor is often below the water table. Disposal in the spoil banks, just prior to reclamation, would generally result in wastes being placed above the water table with less opportunity for interaction with groundwater aquifers. However, infiltration of precipitation and leachate generation may still lead to water contamination with this practice. The generic significance of this impact mechanism is considered similar to that associated with other dry disposal operations.

Impoundment without maintenance of water cover is considered intermediate in potential for water contamination between ponding and dry disposal for all stabilized FGC wastes. This reflects the greater initial water content of the wastes, which are pumped or sluiced to the impoundment, in contrast to dry disposal techniques. This greater water content increases the potential for interaction between ambient surface and groundwater and the waste. As discussed further in Section 4.2.4, leachate generation and discharge can be reduced more effectively with dry handling techniques via disposal site management practices [6,23,24].

Disposal of FGC wastes in underground mines provides mechanisms of potential positive and negative water impacts [19]. Because they are often neutral to basic in pH, FGC wastes may serve to mitigate some instances of acid mine drainage. However, it appears that mechanisms of potential negative impacts discussed for other disposal options would also be operative in underground mine disposal. Specifically, leachate from within the mine, and runoff and/or leachate from any waste-related waters collected and pumped out of the mine would be mechanisms of interest.

2.4.2.3 Air-Related Mechanisms of Impact

Ponding

Wet ponding involves the disposal of slurries of FGC wastes in excavated or diked areas. Because the waste is always covered by water, the only emissions to the ambient air are a result of short-haul trucking, when it occurs if the material is dry; often wet material is transported. Most of the dust emissions of native soil from such trucking would consist of large particles that settle out near the roadside. According to the Clean Air Act as amended, "fugitive dust emissions" of native soil from this type of activity are not subject to Prevention of Significant Deterioration permit review. Revegetation or other activities on the pond after it is filled with waste and water removed (i.e., possible operational phase) may be subject to fugitive dust. Proper planning can minimize this impact.

Dry Disposal

An alternative impoundment procedure is dry disposal wherein the FGC waste is dewatered to a product having the consistency of moist soil. Where dewatering occurs at the FGC system site, short-haul trucking and the use of conveyors are likely means of transport. The waste material is layered in the disposal basin in six-inch to one-foot lifts and compacted using standard earth moving equipment. Compaction serves the purpose of preparing a waste surface that is very resistent to weathering (wind or rain erosion). While the wastes retain at least 5 to 10% moisture, this type of operation does not result in any long-term air quality impact potential. It is possible that the dewatered and deposited wastes after drying may be subject to wind erosion at the surface unless control practices prevent it.

Mine Disposal

As described earlier in Section 2.2.3, in surface mines there are basically three options for the placement of wastes: (1) in the working pit, following coal extraction and prior to return of overburden; (2) in the spoil banks, after return to the overburden but prior to final reclamation of the land; and (3) mixed with or sandwiched between layers of overburden. With the exception of option three, each case has the potential to impact air quality adversely after the waste drier. The extent of actual emission will depend on whether the wind velocity is sufficient to transport the particles (generally more than 16 kph or 10 mph) even after the surface is dry and can be subject to wind erosion.

The air quality impact mechanism associated with underground mine disposal consists mainly of the potential reaction of mine acid drainage with calcium sulfite in the waste, producing sulfur dioxide gas. This reaction is expected to occur only in the initial period following disposal because the buffering capacity of the waste would eventually raise the pH of the mine drainage in immediate contact with it. An additional possible source of gaseous emissions, over the long term, is microbial oxidation.

Atmospheric emission of these gases could correspond to drops in atmospheric pressure, causing the mines to belch gas. This type of emission source would be intermittent and of duration only long enough to allow atmospheric pressure equilibration.

Ocean Dumping

The only adverse air quality impacts associated with this alternative are due to native soil "shake-up" caused by truck haulage over dirt roads and/or wind erosion of a dry FGC waste while being transported. In the former case, regulations exempt the emissions. In the latter, covering and/or transporting moist material would minimize emissions.

2.4.2.4 Potential Mechanisms of Biological Impact

Mechanisms of potential biological impacts from FGC waste disposal are derived from disposal and material characteristics discussed above as mechanisms of potential land-, water-, and air-related impacts. In other words, if one considers land, water, and air impacts as "primary" impacts of disposal, then resulting biological impacts might be termed "secondary." The importance of this concept can be better illustrated in subsequent sections of the report because it implies that control technologies applied to mitigate land, water, and air impacts have the effect of mitigating biological impacts as well.

Mechanisms of potential impact derived from the land impacts of FGC waste disposal can be described by the phrase "direct habitat modification." For each of the land-based disposal options discussed in this report, varying amounts of habitat could be directly modified by the placement of wastes in ares previously occupied by vegetation and wildlife. Underground mine disposal has minimal implications from this standpoint, mostly relating to the transport and interim storage of the wastes. Disposal in surface mines has this type of impact potential only insofar as FGC waste substrates might be more or less supportive of future revegetation and reoccupation by wildlife than other possible reclamation substrates. Wet or dry impoundments and landfills create the most potential for direct terrestrial habitat modification by the mechanism of devotion of previously undisturbed land to FGC waste disposal. The degree of significance of this type of impact mechanism is, by definition, highly site specific, since, for example, some of the devoted land may, in fact, have been greatly disturbed by other activities prior to its use for FGC waste disposal. (This is true for many "captive" sites on utility property.) Over the long term, some land-based disposal options, upon completion, represent a potentially positive mechanism of habitat modification impact. This is because revegetation of these areas can create new habitats that (for a time) add diversity to their surroundings (e.g., a grassland or early succesional shrub community within a forest environment).

Conventional disposal of unstabilized FGC wastes in the ocean has the potential to substantially modify the suitability of substrates as habitat for benthic organisms[31]. The mechanism of potential impact in this instance is replacement of coarse, relatively stable natural substrates with a fine, relatively unstable one. It has been suggested that certain types of stabilized FGC wastes may create desirable new habitats (i.e., artificial reefs) when placed in the ocean[32].

Some of the mechanisms of potential biological impact derived from water-related FGC waste disposal impacts can be referred to as examples of "indirect habitat modification." Examples include the potential impacts of increased volumes of dissolved, suspended (and/or settleable) solids on aquatic biota downstream of supernatant discharges from FGC waste disposal ponds (wet impoundments). The potential impact mechanism of sulfite-related oxygen depletion (discussed above in 2.4.2.2) would have direct and indirect biological impact implications in both ocean and fresh-water systems. Localized dissolved oxygen reductions in these systems could directly impact aquatic biota requiring oxygen for respiration and indirectly affect these and other organisms by affecting the toxicity of other substances in the environment. The release and transport of trace constituents of FGC wastes (especially metals) in aquatic systems creates two potential impact mechanisms of interest: (1) direct toxicity to exposed organisms; and (2) accumulation by exposed organisms leading to subsequent toxicity elsewhere in the food web. In fresh waters, leachate and runoff from disposal areas are the precursors to these potential impact mechanisms. In the ocean, direct discharge would take place, followed by long-term leaching opportunities.

Mechanisms of potential biological impact derived from air-related FGC waste disposal impacts appear to be relatively minor in extent.

In theory, the mechanisms described above (Section 2.4.2.3) could create small zones of increased exposure to particulate and/or gaseous emissions. However, the opportunities for significant increases in exposure risk seem to be severely limited by the combination of disposal locations (e.g., deep mines) and contaminants of interest (fugitive particulates).

2.4.3 Issue Definition Process

2.4.3.1 Introduction

In the broadest, most general sense, the environmental issues associated with FGC waste disposal are defined by the characteristics of the wastes and the disposal options. This level of issue definition is reflected in the general discussion of potential impact mechanisms in Section 2.4.2 above. Further issue definition (i.e., better identification of impact potential) is important in the development of a reasonable strategy for environmental management of these wastes. That is the focus of the R&D efforts described later in this report (4.0). Specific issues are defined by the regulations governing FGC waste disposal, usually in the forms of disposal restrictions, performance criteria, and monitoring requirements. Therefore, the remainder of this section (2.4.3) provides: (1) a status summary of the regulatory framework relevent to issues associated with FGC waste disposal (and discussed in much greater detail in Section 3 of this volume); and (2) a discussion of a process by which issues may be prioritized in the evaluation of the results of environmental assessment studies.

2.4.3.2 Status of Issue Definition by Regulations

A detailed discussion of the status of regulations pertinent to FGC waste disposal is presented in Section 3 of this volume. This section is intended to serve as a means of linking the information presented in Section 3 to the environmental issues discussed throughout Section 2.4.

Table 2.14 summarizes the present status of issue definition by regulation of FGC waste disposal. The major point illustrated by the table is that virtually no specific regulations exist for the sole purpose of governing the disposal of FGC wastes. Such regulations are either pending development (e.g., under RCRA and the Surface Mining Reclamation and Control Act) or exist only in the form of more general restrictions applicable to a variety of waste types. Because of pending decisions in several areas, the degree to which FGC waste disposal impact issues are specifically defined by regulations is in a particularly important state of flux. Pending decisions about the classification of these wastes under RCRA, and about the procedures for regulating "priority" or "toxic" pollutants under the Federal Water Pollution Control Act will help to crystallize the issue definition process when they are made.

In spite of the uncertainties created by the present state of flux in the regulatory process, another significant point illustrated by Table 2.14 is that all of the potential environmental impact issues associated with FGC waste disposal are subject to some form of present or future Federal regulatory attention. Thus, the environmental assessment and other R&D efforts reviewed in this report can be integrated as appropriate into the regulatory framework, rather than existing as "paper studies" in a vacuum.

2.4.3.3 Prioritization of Impact Issues

Given the pending state of regulatory development described above, the authors of this report have had to create certain guidelines for prioritorization of efforts to report evaluations of potential impact issues. In general, an effort has been made to give highest priority to evaluations of potential impact issues associated with well-designed, well-run FGC waste disposal operations. In other words, wherever possible, attempts have been made to identify separately these types of impacts and those that might be characteristic of poorly designed and/or poorly run operations. A third category, consisting of impacts associated with abnormal events, has also been identified.

Table 2.15

Status of Issue Definition by Regulations Governing Disposal of FGC Wastes

	Res. Cons. & Rec. Act	Fed. Water Poll. Control Act	Clean Air Act	Surf. Min. Rec. & Con. Act	Dam Safety Act	OSHA	Marine Prot., Res., Sanct. Act	Safe Drink. Water Act	Coal Mine Health/Safety Act
Physical Stability	P	-	G	G,P	G	G	G	-	G
Land Use Policy	P	-	G	G,P	-	-	-	-	-
Water Quality	P	G,P	-	G,P	-	-	G	P	-
Air Quality	-	-	G	-	-	G	-	-	G
Biological Impact	P	G,P	G	G,P	-	-	G	-	-
Potentially Applicable Disposal Options	1,2	1,2,3,4	1,2,3,4	3,4	1	1,2,3,4,5	5	4	3,4

Key to Descriptions of Status:
S = Specific regulations exist for FGC waste disposal.
G = General regulations exist for waste disposal.
P = Further regulations authorized but pending.

Key to Potentially Applicable Disposal Options:
1 = Impoundment
2 = Landfill
3 = Surface Mine
4 = Underground Mine
5 = Ocean Dumping

In the absence of specific regulations, "good design" and "good practice" are more difficult to characterize, since both are often practically defined on a site-specific basis by the amount a disposer needs to (or is willing to) pay. Accordingly, many of the early environmental assessment studies of FGC waste disposal have failed to characterize the design or operational efficiency of the operations under investigation. This introduces many caveats into the review of such studies presented below in Sections 4.2 and 4.3. Additionally, it requires that some of the discussion of potential impacts of well-designed, well-run disposal operations appears in Section 4.4, where possible mitigative control technology for disposal operations is assessed.

2.5 Site Selection, Design and Practice

Increasingly stringent environmental and economic constraints place increased emphasis on three aspects of FGC waste disposal:

- Site selection,
- Design, and
- Operational practice.

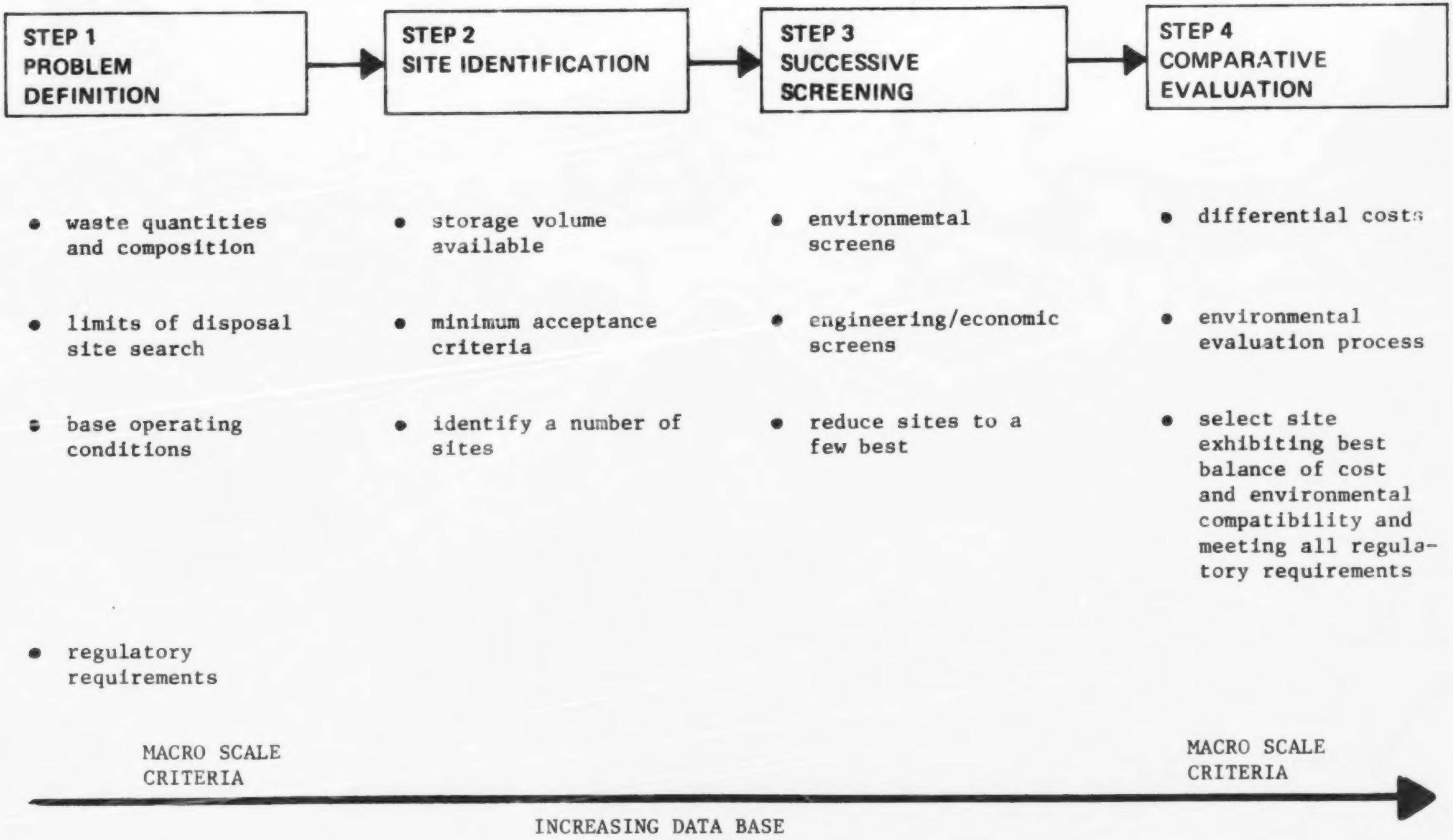
For new facilities full optimization of each of these is essential. In this subsection some of the important considerations in each of the above will be discussed.

2.5.1. Land Disposal

2.5.1.1 Site Selection

Siting of major solid waste disposal facilities like FGC wastes is drawing substantial regulatory interest. Environmental impact, as well as engineering/economic factors, must now be assessed. In essence, the balance between potential environmental impact and costs must be part of the decision-making process in the selection of an FGC waste disposal site. Further, the requirements under RCRA and state regulations are baselines that define acceptable environmental standards. The identification and evaluation of FGC waste disposal facilities is becoming a major factor in siting new coal-fired utility plants. Many of the environmental and engineering/economic evaluations conducted in power plant site selection endeavors are equally applicable to the siting of FGC waste disposal facilities. Also, much of the technical and environmental expertise required in power plant siting is also required to identify and assess solid waste disposal sites. Figure 2.14 presents a logic diagram of an FGC waste site selection process.

The three basic categories of parameters to consider in disposal and land reclamation site evaluations are regulations, engineering/economics and environmental. Table 2.16 presents a partial listing of the categories and their respective parameters. The environmental evaluation process generically covers the methodology to be employed to tabulate environmental impacts. In general, the importance of


STEP 1
PROBLEM DEFINITION
STEP 2
SITE IDENTIFICATION
STEP 3
SUCCESSIVE SCREENING
STEP 4
COMPARATIVE EVALUATION
• waste quantities and composition
• limits of disposal site search
• base operating conditions
• regulatory requirements
• storage volume available
• minimum acceptance criteria
• identify a number of sites
• environmemtal screens
• engineering/economic screens
• reduce sites to a few best
• differential costs
• environmental evaluation process
• select site exhibiting best balance of cost and environmental compatibility and meeting all regulatory requirements
MACRO SCALE CRITERIA
MACRO SCALE CRITERIA
INCREASING DATA BASE

Source: [100]

Figure 2.14 FGC Disposal Site Selection Process Logic Diagram

Table 2.16

FGC Waste Disposal Site Evaluation Parameters

Environmental

- Air Quality
  - dust nuisance
- Aesthetics
  - visual sensitivity
  - natural screening available
- Aquatic Ecology/Water Quality
  - impact on surface water
  - impact on ground water
  - sensitivity
  - chemical releases via leachate
- Land Use
  - present
  - projected
  - proximate
  - ultimate
- Noise
  - sensitive receptors
  - natural shielding
  - transportation and operation
- Public Health and Safety
  - fill stability
  - transportation disruptions
- Socio-Economic
  - loss of land productivity
  - people affected
  - increased value of reclaimed spoil lands
- Terrestrial Ecology
  - critical habitat
  - threatened or endangered species
  - sensitivity of vegetation

Engineering/Economic

- Hydrology
  - flooding potential
  - surface water protection
  - ground water protection
- Site Development
  - surface and subsurface drainage
  - capacity and topography
  - fill design
- Transportation and Access
  - barge
  - railroad
  - truck
  - conveyor (belt or pneumatic
  - pipe
  - hauling distance
- Geology
  - depth of overburden
  - ground water depth
  - soil types, physical/chemical characteristics
  - need for impermeable liner
- Treatment Equipment
  - compaction/grading
  - leachate
  - impermeable liners
- Land Availability and Cost

Regulatory

- Federal
  See Figure 3.1
- State
  As Applicable
- Local
  As applicable

Note: This is a partial listing and for illustrative purposes only.

environmental parameters relative to each other and the magnitude of the potential impacts need to be assessed. The Environmental Evaluation Matrix (EEM) developed by Leopold et al.[101] is one example.

2.5.1.2 Rationale for Good Design/Good Practice

Increasingly severe environmental and economic constraints place enormous emphasis on planning the operation taking into account all the constraints. For optimum design/practice of FGC waste disposal, important considerations are:

a. What environmental impacts could occur and must be mitigated if possible by design/practice? The principal issues may include:

   - Water-groundwater pollution by leachate; surface water pollution by runoff and/or leachate; increased water use; water pollution caused by dike failure or severe flooding.
   - Air - fugitive emissions from exposed surfaces of ash or dry sludge; emission of gases.
   - Land - constraint on future land uses; instability during operation.
   - Other - hazards to personnel and equipment.

   Impact issues are discussed further in Section 2.4.8 and Section 4.0. The only emphasis in this subsection is their importance on design of facilities.

b. Technical/economic consideration to optimize economics and maximize safety. Basic approach may include:

   - Maximization of density - compaction,
   - Minimization of handling - co-disposal of ash and sludge,
   - Increase of density (solids content) to increase strength/stability and decrease compressibility,
   - Increase of solids content to improve handling properties, and
   - Stabilization of mixed wastes with additives to form dikes and consideration of a lining system, if needed, to contain wastes and prevent leaching and migration of pollutants.

The overall objectives of good design/practice are:

- Containment of the wastes, including leachate as much as practicable. Long term stability of the waste places in the disposal site is essential.
- Maximization of the amount of wastes/unit volume.
- Minimization of handling problems.
- Facilitation of water recycle as much as practicable.
- Minimization of fugitive emissions.
- Prevention/elimination of operator/equipment hazards.

Several researchers and designers have considered all these in developing broad approaches. FGD wastes can be broadly categorized into three types reflecting differences in chemical and engineering properties. (This is discussed in more detail in Volume 3.) The basic categories of FGD wastes are:

- Sulfite-rich wastes. The particles are needles, platelets or agglomerates.
- Mixed sulfate/sulfite wastes. The particles are needles, platelets or cleavage fragments.
- Sulfate-rich wastes which are needles or cleavage fragments.

Coal ash (fly ash and bottom ash) does exhibit varying characteristics but not in a manner as to permit analogous characterization. Dry disposal of ash, co-disposal of ash, and FGD wastes and stabilization processes for FGD wastes (which usually employs fly ash and lime) are likely to be widely processed in future. For each of the above categories, a number of design/practice choices are available. Typical questions defining the options are:

- Pond wastes or compact in landfill?
- Dewater or mix dry ash with FGD waste for landfilling?
- For dry disposal, lift thickness for compaction?
- Slope angle vs. slope height for dikes/fills?
- Use of stabilization of FGD wastes for containment dikes?
- Material for liner if needed; stabilized wastes, clay, synthetic?
- Thickness of the liner?
- Monitoring methods and degree?

Some general comments on good design/good practice taking into account the three categories of FGD wastes and the options defined above are offered in the remainder of this subsection. These are broadly applicable but need to be modified in light of site-specific considerations.

2.5.1.3 Sulfite-Rich Wastes

For sulfite-rich wastes, if co-disposal is indicated, it would appear to be advisable to convey low-solids sludge to a disposal site and mix it there with dry fly ash, for a new plant without wet fly ash transfer facilities. It is not likely that sulfite-rich wastes would be suitable for landfill except with stabilization; sulfite-rich wastes are weak, compressible and susceptible to liquefaction under dynamic loading. Sulfite-rich wastes most likely would be ponded, injected into deep mines, placed in surface mine pits and spoil banks particularly with stabilization. In the future, placement of FGC wastes in managed fills is likely to be encouraged. This may require stabilization of sulfite-rich wastes in many cases.

In any event, sulfite-rich wastes must be contained. In ponds, this would require use of soil or stabilized wastes in containment dikes. Use of soil to construct dikes is a common practice and requires no innovation. Use of FGD waste, FGD waste plus ash or stabilized waste to construct dikes would require determination of FGD waste and ash properties (shear strength parameters, compressibility, and permeability as well as compaction behavior). Good design would include specification of slope angle as a function of proposed slope height for containment dikes, with the function determined on the basis of previous laboratory tests. Containment dikes would be constructed in lifts (layers), with compaction of the lifts to a density specified on the basis of compaction tests. The dikes would be used to support deposited wastes but may require a lining to prevent passage of leachate. Even an embankment built of stabilized sludge would contain cracks and fissures, so a lining may be required or desirable. The least expensive lining would be a layer of plastic clay at least 24 inches thick compacted at a moisture content well above optimum moisture content as determined by Standard Proctor test (see Volume 3 for test references). Placement of the clay on the inside of the dike would ensure that seeping liquid would carry the clay into any cracks in the dike and create a seal. Compaction of the wastes themselves would not be possible unless the sludge (or mix) were dewatered to a solids content of at least 70% (indicated by tests in 1977-78 at Plant Scholz). This does not seem to be economically viable for most situations at the present time. Compaction would be advisable at a plant site if this operation improved the waste behavior sufficiently to minimize environmental impacts and/or permit a future use of the site which would return revenues adequate to defray compaction costs, and the costs of preparatory dewatering. It is doubtful that increase in density associated with compaction in and of itself would be cost effective (through increase in amount of waste placed on each unit of area).

An important design consideration is to insure that FGC wastes disposed of on land will remain ultimately stable even if inundated by flooding or other conditions of sustained hydraulic discharge. This is particularly important if stabilized FGC wastes are employed as diking or liner materials at the disposal site. Regulations under RCRA on this issue are under review.

Good design would include provisions for monitoring groundwater quality and surface water quality. Current EPA Guidelines [8] on this issue were relaxed recently and would apply to FGC wastes [8]. Monitoring wells could be installed in such a way that if a leak were discovered, the monitor well could be pumped to remove contaminated water. The area of the disposal site could be graded to cause water to flow to the locations of the monitor wells. The annular space between the well casing (perforated) and the natural soil could be filled with sand-gravel when the temporary hole casing is in place so that a collection zone was formed around the well pipe. A layer of sand-gravel on the surface, around the well pipe, could channel leachate to the well; the site lining would then be placed over the sand-gravel collection zone. If needed, surface waters could be collected within the disposal site;

i.e., precipitation falling on the site could be collected by standard temporary drainage control techniques employed at large-area construction projects. All contaminated waters would be retained for recycle and/or treatment.

To facilitate uniform placement of wastes and recycle of supernatent, a floating boom could be employed. The boom would be moved daily (or sooner) in a pattern devised prior to construction, to prevent formation of large delta features. At the present time, it appears advisable to spread the wastes as thinly as possible to maximize dewatering by evaporation and/or freezing-thawing cycles. Consideration should be given to depositing FGD sludge in thin layers between layers of fly ash; the more pervious fly ash layers would serve as drainage zones to accelerate dewatering and consolidation of the sludge. Layering of ash between sludge also may increase the overall stability of the wastes deposit, but detailed technical and economic evaluation would be required prior to use of such a technique.

Good design of a waste disposal facility would include planning of temporary haul roads, usually included via the containment dikes, to permit equipment access to all reaches of the disposal site.

Also, provisions could be made to use some of the supernatent for dust control in dry climates where spreading wastes in thin layers over large areas could lead to fugitive emissions; a moisture content of only 15-20% should be adequate for dust control. If wastes are placed in alternating layers (sludge, ash, sludge, ash...) the disposal operation should be designed so that sludge is placed over ash as soon as possible; i.e., the time of exposure of unmixed ash should be minimized.

During design of a disposal site, consideration should be given to designing the placement sequence to meet site-specific needs: placement on a small area to full depth within a short time to free that area for another use; or placement of wastes first in those parts of the disposal site farthest from the plant (source) to reduce the burden (length of pipelines, pumping pressure, etc.) on aging transport equipment; or use of land of least value first in hopes that technology will change (no more scrubbing or sludge of better behavior or dry wastes...) and more valuable land can be better used; etc.

Hazards to personnel and equipment would be minimized by placement of sludge in thin layers, compared to ponding to great depth very rapidly.

Because of the nature of sulfite-rich wastes (weak, compressible, unstable), a general rule in design would be to use soil, stabilized wastes or a mix of materials to contain unfixed materials and to rely on the unfixed wastes to carry no load but rather to impose loads on containment facilities.

2.5.1.4 Mixed Sulfite/Sulfate Wastes

For mixtures of sulfite/sulfate wastes, it is anticipated that the sulfite-rich materials will predominate or govern the behavior of the mixtures in much the same way that silt-sized particles greatly influence the behavior of silty sands. Obviously, the degree to which the sulfite-rich wastes influence the behavior of the mixture depends on the sulfite/sulfate ratio, but a minor fraction (15-20%) of sulfite-rich wastes in a mixture may virtually govern the permeability, shear strength and compaction behavior of the mixture (these comments assume that the sulfate-rich wastes will tend to consist of larger particles of more equal dimensions as compared to sulfite platelets or needles; if these assumptions are at variance with the actual conditions at a given site, the behavior of the wastes at that site may differ drastically from that suggested here). In a mixture, the smaller and/or weaker particles will tend to govern behavior. Mixtures of sulfite-sulfate wastes (assuming the sulfite to be smaller and weaker particles) may closely resemble pure sulfite-rich wastes in hydraulic properties (dewatering and permeability) and may be much weaker and more compressible than pure sulfate-rich wastes.

For these reasons, disposal of mixtures of sulfite/sulfate wastes may be just as difficult as disposal of sulfite-rich wastes alone.

2.5.1.5 Sulfate-Rich Wastes

Sulfate-rich wastes are usually larger in particle size, with bulkier, less deformable crystals. Such wastes should dewater sufficiently by gravity drainage, filtration, and/or mixing with dry fly ash to permit compaction of the material in self-supporting landfill configurations. Nevertheless, it may still be necessary to contain leachate in site-specific instances. Provisions for lining disposal sites, collecting surface waters on-site, monitoring groundwater quality and monitoring surface water quality should be considered in an analogous manner to those employed for disposal of sulfite-rich wastes.

In general, mixing FGD waste with ash may be beneficial for sulfite-rich materials or mixtures of sulfite/sulfate wastes, but mixing ash with sulfate-rich wastes may not be advisable unless site-specific benefits of co-disposal justify such a practice. It may be noted that ash usually has higher levels of trace metals and hence an environmental trade-off is involved in co-disposal. That is, the leachate from co-disposal would often be richer in heavy metals than FGD wastes alone.

2.5.1.6 RCRA and Planning FGC Waste Disposal

The Resource Conservation & Recovery Act of 1976 (RCRA) is the principal federal legislative framework impacting solid waste disposal on land. RCRA and other pertinent regulatory framework are discussed in Section 3. However, some comments on RCRA and FGC waste disposal design/practice may be pertinent here.

> Proposed regulations under the RCRA were issued on December 18, 1978 [8], and are under review. Potentially, these could undergo significant modifications prior to scheduled promulgation in December 1979. The criteria for identifying hazardous wastes include characteristics such as ignitability, corrosiveness, reactivity (e.g., strong oxidizing agents), and certain aspects of toxicity. The protocol for toxicity (which is the most pertinent to FGC wastes) includes subjecting the waste to an extraction procedure (EP), followed by chemical tests for metals and pesticides.
>
> Based on RCRA guidelines published in December 1978, the steps to determine RCRA related requirements for FGC waste disposal are:

a. The proposed Extraction Procedure (EP) specified in Section 3001 protocol will be employed on each FGC waste to determine if it passes or fails the protocol.

b. If a waste passes the tests, there will be no federal requirements governing waste disposal under RCRA. However, guidelines are offered under Section 4004. Individual states are required to adopt and enforce Section 4004 to regulate FGC waste disposal if they wish to receive federal financial aid under Subtitle D of RCRA.

c. If an FGC waste fails the tests, it will be considered a special waste. Then, only site-selection, monitoring, and record-keeping standards of Section 3004 (hazardous wastes disposal) will apply. Design standards under Section 3004 as currently proposed are not required in any case for FGC waste disposal.

2.5.2 Ocean Disposal

Ocean disposal of FGC wastes is not now practiced. Ongoing studies and assessment are discussed in Section 2.3. If at a future date ocean disposal of FGC wastes is practiced, site selection, design and practice of the waste disposal operation would require considerations analogous to those discussed for land disposal. Engineering or design approaches for ocean disposal require further study.

3.0 REGULATORY CONSIDERATIONS

3.1 Regulatory Framework Overview

FGC wastes are generated when stack gas scrubbing is employed to meet the requirements of the Clean Air Act as amended in 1977. Once generated, their transportation, handling, and ultimate disposal may be regulated under a complex framework of environmental laws and regulations which are implemented by different offices within an assortment of federal, state, and local agencies. The implication of the myriad regulations governing FGC wastes is that removing contaminants from flue gas is not the ultimate resolution of an environmental problem. Rather, it is the transformation of the problem into another form which, it is hoped, will be more manageable.

The quantities of FGC wastes which will be generated in the future depend critically on the implementation of two recent federal laws, the Clean Air Act of 1977 and the National Energy Act. The National Energy Act is composed of five separate bills, of which the most significant in relation to FGC waste generation are the Power Plant and Industrial Fuel Use Act of 1978 and the Natural Gas Policy Act of 1978.

Implementation and enforcement of the Clean Air Act is expected to increase the quantities of FGC waste generated by reducing allowable emissions of particulates and SO_2 for new power plants. The solid waste impacts of alternative levels of SO_2 and control have been considered by Leo & Rossoff [61]. Existing plants may also be affected by state implementation plans for TSP and SO_2. Additional generation of FGC wastes by tightening environmental regulations is thus likely. Moreover, low sulfur coal that now does not require desulfurization may require FGD systems in the future. Regulations under the Clean Air Act are expected in mid-1979.

The Power Plant and Industrial Fuel Use Act is expected to increase the amounts of FGC waste generated by its prohibition of the burning of oil and gas in new power plants, and by requiring some existing plants to convert to coal from oil and gas. The Natural Gas Policy Act will tend to encourage the use of coal and oil by industrial users, by forcing the greatest burden of natural gas price increases on industrial and utility users, and by classifying them as lower priority than residential and agricultural users in the event of natural gas curtailments. Some users may convert to alternative fuels in the face of high priced gas with an uncertain supply. The implementation of NEA has barely begun, and any assessment of its impact on FGC waste generation is premature at this time. The provisions of NEA are discussed in Power, October, 1978, pages 68-70. NEA strengthens the coal-conversion-forcing provisions of the Energy Supply and Environmental Coordination Act of 1974 by transferring the burden of proof in any coal conversion dispute from government to industry. Under NEA, a utility must convert to coal unless it can demonstrate infeasibility. Infeasibility may be based on fuel availability, site limitations, environmental requirements, state and local requirements (e.g., building codes), etc.

Most federal environmental law enacted in this decade is implemented and enforced by the Environmental Protection Agency (EPA). The EPA now has broad control over all "phases" of the environment: air, water, and solid wastes. It has been observed, since the passage of the Safe Drinking Water Act, and the Resource Conservation & Recovery Act, that EPA has authority to protect all phases of the environment in a balanced program via coordination of regulatory activity affecting several interacting media. Other branches of government, particularly the Army Corps of Engineers, the Department of Labor, the Department of Transportation, the Department of the Interior, state and local governments maintain jurisdiction over many activities which significantly affect the environment and FGC waste disposal. In many instances, these separate agencies attempt to coordinate policies and regulations affecting the environment, but organizational mechanisms for effecting such coordination are absent or poorly defined.

An emerging issue for environmental regulators is the total impact across all environmental media (air, water, land), and the human environment--including availability of energy and water, and the social infrastructure--of regulatory action which specifically addresses a problem in one environmental "box." For example, does the treatment of water effluents entail an energy cost, with required generation of that energy leading to more serious environmental and economic problems? Is SO_2 in the air more detrimental to health than FGD sludge leachate and other scrubber-related effluent streams? Much environmental science, engineering, and regulation has been developed with an eye to a single environmental compartment. for numerous reasons, including the maturing of the environmental sciences from media or discipline oriented specialties, and the topical nature of environmental problems.

Recent environmental laws have different requirements for consideration of cross-media and environmental impacts with the Clean Air Act having the least requirements for such considerations. Nonetheless, the laws implicitly, and in some cases, require consideration of economics, and several provide mechanisms for consideration of related environmental impacts. A coordinated approach aimed at maximizing the total environmental benefits of a regulatory program will face technical, institutional, and budgetary constraints. The technical and budgetary constraints are closely related: it is extremely difficult to predict the gamut of environmental consequences of a specific action; consequently, the cost of such an assessment is high. In some cases, the state of the art is not adequate to predict the consequences, regardless of cost and of available resources.

Institutional constraints on a cross-media or "global" approach arise where different departments, agencies, and offices are responsible for specific environmental "boxes:" air, water, solid waste, mines, waterways, etc. Since EPA has statutory authority in each of the major "boxes"--air, water, solid waste--this agency has the greatest opportunity for a "global" approach, but the establishment of interaction between offices responsible for the separate media has been reported by some observers to be a significant bureaucratic problem (Walsh, 1978, Science, V. 202, p. 600). The research arm of EPA (Office of Research & Development) has adopted a "global" approach in evaluating total environmental impact on an industry-by-industry basis with a goal of evaluating the total impact of specific actions, controls, etc. This base of information has expanded over the last five years and is gradually being reflected in regulatory policy. Official mechanisms for incorporating a broad base of cross-media information to bear on the regulatory process have been slow to develop, and it is likely that individual initiatives continue to be the most effective mechanism for coordinating regulatory policy to the end of minimizing total cross-media environmental impacts.

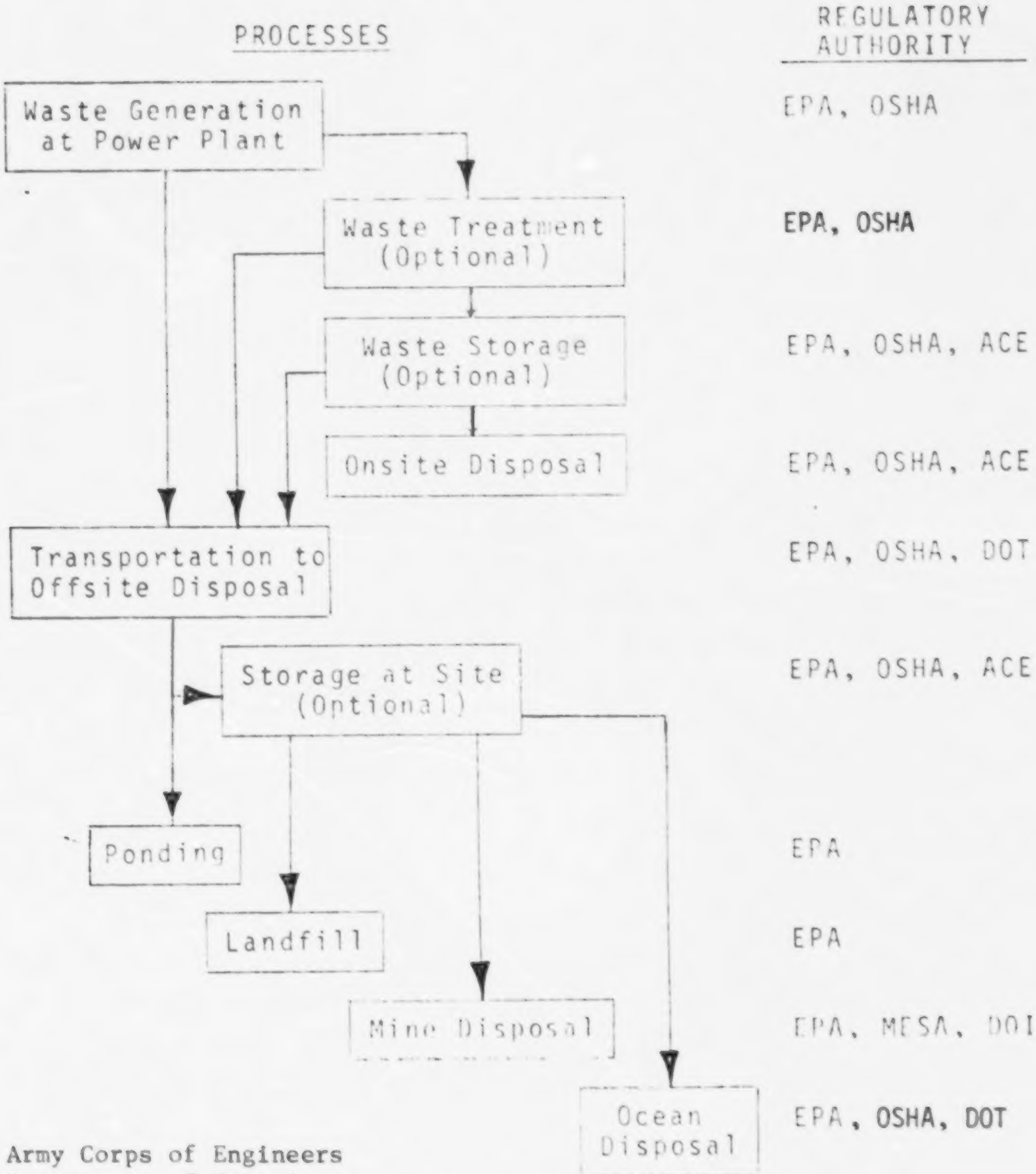
Some exemplary provisions of recent environmental legislation which force a cross-media approach include:

- The requirements of Sections 304 and 306 of the Clean Water Act (FWPCA) that EPA consider "non-water quality environmental impact (including energy requirements)" in the establishing of effluent limitations and new source performance standards,
- The requirement of Section 1008 of the Resource Conservation and Recovery Act that solid waste management guidelines provide for the protection of ground and surface waters and ambient air, and
- The provision of TSCA which directs the Office of Toxic Substances to consult with other offices within the agency before formulating regulatory strategy.

It is recognized that in the case of RCRA, the Office of Solid Waste (OSW), has responsibility for all media - a possible result is that OSW's air and surface water related standards for disposal sites could be different from other federal or state standards for the prevention of air/water pollution from types of facilities. In some instances, this could potentially create jurisdictional impediments in individual permitting actions.

Figure 3.1 provides a "cradle-to-grave" schematic of FGC waste generation, handling, and disposal identifying federal regulatory agencies with jurisdiction over step processes which involve changes in physical/chemical properties or location. The right side of the figure presents the federal regulatory authority with jurisdiction over that process.

Ash and SO_2 removed from stack gases are not destroyed, but simply collected and transformed. Based on authority derived from the Clean Air Act as amended in 1977, EPA is requiring higher levels of control of particulates and SO_2. Based on authority derived from the Federal Water Pollution Control Act, also administered by EPA, some derivatives of these wastes may not be discharged in appreciable quantities to navigable surface waters. Recognizing that only a small fraction of such wastes is put to beneficial use in the United States, land-based disposal is, indirectly,


PROCESSES
REGULATORY AUTHORITY
Waste Generation at Power Plant
EPA, OSHA
Waste Treatment (Optional)
EPA, OSHA
Waste Storage (Optional)
EPA, OSHA, ACE
Onsite Disposal
EPA, OSHA, ACE
Transportation to Offsite Disposal
EPA, OSHA, DOT
Storage at Site (Optional)
EPA, OSHA, ACE
Ponding
EPA
Landfill
EPA
Mine Disposal
EPA, MESA, DOI
Ocean Disposal
EPA, OSHA, DOT

ACE - Army Corps of Engineers
DOI - Department of Interior
DOT - Department of Transportation
EPA - Environmental Protection Agency
MESA - Mine Enforcement & Safety Administration
OSHA - Occupational Safety & Health Administration

Figure 3.1 FGC Wastes - Federal Regulatory Chart

required by the laws mentioned above and administered by EPA (OSHA also has regulatory authority over issues pertaining to the safety and health of workers at the generation site, but this authority is tangential to the issues highlighted here).

Once generated, the wastes may be treated and/or temporarily stored. FGC waste treatment is not directly regulated or required by law, although constraints on disposal of sludge encourage, and establish technical standards for, waste treatment. These constraints on sludge disposal derive from existing regulations, and speculatively, from anticipated waste disposal regulation.

Temporary storage, whether at the point of generation, disposal or during interim transport, is regulated in much the same way as disposal discussed below.

Authority to regulate the transportation of wastes rests with the Department of Transportation, OSHA, and EPA under a variety of laws, and there is little experience to indicate how presumptions of overlapping authority might be resolved. One relevant example is in the management of spills of hazardous materials in the nation's waterways where both EPA and the U. S. Coast Guard (DOT) have statutory authority: EPA concentrates on identification of sources and subsequent legal action, while the Coast Guard performs emergency response and clean up.

Most viable disposal options are land-based and there are numerous regulatory bodies with authority over some phase of land-based disposal. The broadest-based authority rests with EPA and particularly with the Office of Solid Waste which administers the Resource Conservation and Recovery Act of 1976. The Office of Solid Waste is responsible for setting guidelines for state solid waste management plans, efficiency criteria for disposal of non-hazardous waste and minimum national standards for the handling of hazardous wastes. It is also responsible for deciding what constitutes a hazardous waste. This decision is pertinent to the level of control required and the ultimate regulatory authority over a given waste material: the states are the ultimate authority for the handling of non-hazardous wastes, while OSW has much more direct control over hazardous waste management.

EPA also administers the Safe Drinking Water Act (Office of Water Supply) and the Federal Water Pollution Control Act (Office of Water Programs) which are significant to land-based disposal of FGC wastes. OWS sets national drinking water standards and regulates the underground injection of fluids in wells. The

Office of Water Programs administers the national permitting authority for point source waste discharges to navigable waters. RCRA authority is superceded by the Marine Protection Research & Sanctuaries Act, the Hazardout Material Transportation Act, FWPCA, and SDWA for all activities and substances covered by those acts.

It should further be emphasized that the separate states all maintain varying degrees of authority under all the federal environmental legislation highlighted above. The states may administer state plans with relative autonomy (e.g., non-hazardous solid waste management criteria where OSW defines and prohibits open dumping, writes suggested guidelines and controls allocation of funds to the states) or, at the other extreme, may administer a state program which must be consistent with or more stringent than national standards set by EPA. Under all the important federal environmental statutes, EPA can assume certain regulatory authority if the state neglects to implement and enforce a plan or if the state's actions are inconsistent with the objectives of the act, as interpreted by EPA.

Other important federal statues which may be used to regulate disposal of FGC wastes are the Surface Mine Control & Reclamation Act (administered by the Office of Surface Mining, Department of Interior), the Dam Inspection Act (administered by the U. S. Army Corps of Engineers), the Federal Coal Mine Health & Safety Act (Mining Enforcement Safety Administration), the Occupational Safety & Health Act (Occupational Safety & Health Administration), and the Hazardous Materials Transportation Act (Department of Transportation).

Of these the Surface Mine Control & Reclamation Act is likely to be significant, based on the potential for diposal of sludge and ash generated at mine-mouth power plants, during the reclamation of surface mines. The authority of the Office of Surface Mining is comprehensive, and the proposed regulations which have been generated to date are similarly comprehensive. The OSM/DOI proposed regulations are different from the OSW/EPA regulations in terms of definitions and regulatory strategy. For example, definition of "waste" and "toxic" in the OSM/DOI regulations are not equivalent to those in the OSW/EPA regulations. While OSW/EPA regulations protect "usable aquifers" from "endangerment" the surface mining regulations require the protection of "groundwater systems" from changes in flow or quality. SMCRA does not supercede FWPCA, or the Clean Air Act. Its relationship to RCRA is not spelled out in either law, although coal wastes are regulated under MSCRA.

An ultimate or joint authority over FGC waste disposal in surface mines has not been fully established at this writing, making it difficult to assess the regulatory environment under which waste disposal in surface mines will occur.

The basis for the discussion to follow is the existing and anticipated regulatory environment governing the disposal of flyash and FGD sludges. However, the discussion of: "Possible future regulations: A focus on priority pollutants?" suggests a future solid waste disposal problem. If removal of priority pollutants from waste water streams is required in future regulations pursuant to the settlement agreement and the Clean Water Act of 1977, a number of potentially toxic metals initially cleaned from flue gas will be collected in solid form from wastewater streams. Disposal of these wastes would be regulated under RCRA, possibly under the hazardous waste restriction of Subtitle C. As is the case for other constituents of flue gas, ultimate isolation of these chemicals from the biosphere can only be accomplished through diligent controls and progressive immobilization. All future initiatives to require more stringent control of air and water effluents must be considered in relation to the solid waste impacts.

The discussion to follow is organized according to impact issues as listed in Table 3.1, which includes legislation directly relevant to the various impact issues.

3.2 Groundwater Related

The most important federal laws pertaining to potential groundwater contamination attendant to the disposal of FGC wastes are the Resource Conservation and Recovery Act of 1976 (RCRA), the Safe Drinking Water Act of 1974 (SDWA), the Surface Mining Control and Reclamation Act of 1977 (SMCRA), and the Federal Water Pollution Control Act as amended in 1977, (FWPCA).

3.2.1 Resource Conservation & Recovery Act and Anticipated Regulations

3.2.1.1 Overview

RCRA (PL 94-580) provides for the regulation of the disposal of solid and hazardous wastes. The regulatory framework governing the disposal of FGC wastes will depend on the classification of these wastes as "hazardous" or merely "solid" (non-hazardous) wastes. Federal regulatory

Table 3.1

Regulatory Framework for Coal Ash and FGD Sludge Disposal/Utilization

Impact Issue	Legislation	Administrator
Groundwater Contamination	• Resource Conservation and Recovery Act of 1976	• Environmental Protection Agency, Office of Solid Waste
	• Safe Drinking Water Act of 1974	• Environmental Protection Agency, Office of Water Supply
Surface Water Contamination	• Clean Water Act	• Environmental Protection Agency, Office of Water Programs
	• Marine Protection Research and Sanctuaries Act	• Environmental Protection Agency, Office of Marine Protection
	• Resource Conservation & Recovery Act of 1976	• Environmental Protection Agency, Office of Solid Waste
Physical Stability	• Surface Mining Control and Reclamation Act of 1977	• Office of Surface Mining Reclamation and Enforcement, Department of Interior
	• Dam Safety Act of 1972	• Army Corps of Engineers, Department of Defense
	• Federal Coal Mine Health and Safety Act of 1969	• Mining Enforcement Safety Administration, Bureau of Mines, Department of Interior
	• Occupational Safety and Health Act of 1970	• Occupational Safety Health Administration, Department of Labor
	• Hazardous Materials Transportation Act of 1975	• Department of Transportation
Fugitive Air Emissions	• Clean Air Act of 1970 and its Amendments of 1977	• Environmental Protection Agency, Office of Air Programs

Table 3.1 (Continued)

Regulatory Framework for Coal Ash and FGD Sludge Disposal/Utilization

Impact Issue	Legislation	Administrator
Fugitive Air Emissions cont'd	• Federal Coal Mine Health and Safety Act of 1969	• Mining Enforcement Safety Administration, Department of Labor
	• Resource Conservation and Recovery Act of 1976	• EPA, OSW
	• Occupational Safety and Health Act of 1970	• Occupational Safety and Health Administration, Department of Labor
Marketing and Utilization	• Toxic Substances Control Act of 1977	• Environmental Protection Agency, Office of Toxic Substances

authority is more comprehensive for the former: standards for generators, transporters, and operators of disposal facilities will be more stringent; and disposal of hazardous wastes is expected to be substantially more costly [45].

RCRA is intended to ensure a broad multi-media approach. The overall intent is to integrate to the maximum extent practicable all provisions of RCRA with appropriate provisions of the other Acts of Congress which give EPA regulatory authority. One of the ways EPA has chosen to integrate RCRA with the Safe Drinking Water Act (SDWA), the Clean Air Act (CAA), and the Clean Water Act (CWA) is through the use of Human Health and Environmental Standards. Each of them - the groundwater, surface water, and air standards - establishes an overriding standard for treatment, storage, and disposal facilities by incorporating relevant limitations established under those acts.

Solid wastes are defined in Section 1004 of the act as "any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material resulting from industrial... operations... but does not include... industrial discharges which are point sources subject to permits under Section 402 of Federal Water Pollution Control Act as amended..."

Hazardous waste is defined in the same section as "a solid waste, or combination of solid wastes, which because of its quality, concentration, or physical, chemical, or infectious characteristics may:

a. Cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapitating reversible, illness; or

b. Pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported or disposed of, or otherwise managed."

Subtitle C of the Act - Hazardous Waste Management - requires the EPA to promulgate regulations identifying the characteristics of hazardous waste and to list specific hazardous wastes "taking into account toxicity, persistence, and degradability in nature, potential for accumulation in tissue, and other related factors such as flammability, corrosiveness, and other hazardous characteristics," (Section 3001 (a)).

Regulations attendant to Subtitle C were proposed on December 18, 1978. These are proposed regulations and may be modified prior to promulgation by December 1979. There are two separate, but related, issues involved in determining whether a waste will be regulated, under Subtitle C, as hazardous:

- Identifying the characteristics of hazardous wastes, and
- Listing specific wastes as hazardous.

According to the December 18, 1978 [8] draft, the Office of Solid Waste will regulate on the basis of both the list of hazardous wastes and the characteristics. If a waste is listed, it is presumed to be hazardous. If a generator believes that his listed waste is not hazardous, the burden of proof falls on him to demonstrate that it is not hazardous according to its characteristics. On the other hand, if a waste is not listed but the generator has reason to believe his wastes are hazardous, he is required to test these wastes for the suspected failing characteristics. It is anticipated by the EPA that many utilities will test their wastes to determine whether or not they can be considered hazardous under the regulations.

FGC wastes are not listed as hazardous in the December 18, 1978, proposal. However, in the section entitled "Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities," section 250. 46-2 defines a limited subset of these regulations which are applicable to "any utility waste* which is defined as a hazardous waste under Subpart A" where Subpart A is the proposed regulations pertaining to identification and listing of hazardous wastes. This subset of regulations will be discussed in more detail below. The key issue here is whether this specification of utility wastes as a special waste in the hazardous waste regulations is sufficient grounds to say that generators of these wastes (utilities) "know or have reason to believe" that their waste may be hazardous. In that case, utilities would be required to test their waste and report these tests to EPA. Otherwise, FGC wastes would effectively be exempted from hazardous waste regulation under Subtitle C.

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* Utility waste is defined as fly ash, bottom ash, and flue gas desulfurization sludges.

The December 18, 1978, proposal for identifying the characteristics of hazardous waste defined a number of standard protocols. The most important one for FGC wastes is the Extraction Procedure (EP) for obtaining a leachate elutriate. If the elutriate contains any substance for which a threshold has been established, then the waste is hazardous. Interim threshold standards have been set for As, Ba, Cd, Cr, Pb, Hg, Se, Ag and several pesticides based on the National Interim Primary Drinking Water Standards. It is expected that in the future, thresholds will be established for other contaminants. Test programs have been ongoing at Oak Ridge National Laboratory [46]. It appears [42] that preliminary tests on some TVA Shawnee ash samples indicate that these samples can potentially pass these tests. The proposal also indicates that other water quality criteria (e.g., those for protection of aquatic organisms) are being considered for future use in conjunction with the EP. Figure 3.2 outlines the schematic as regards FGC wastes in terms of regulatory requirements under RCRA. Under the special waste provision, engineering standards for disposal of hazardous wastes under Section 3004 as currently proposed would not apply to FGC wastes until such time as specific standards are promulgated for those wastes.

One possible course of event in response to these regulations is that individual utilities around the country would test their wastes according to the EP, and some of these tests would indicate that the wastes have the characteristics of a hazardous waste. If a substantial portion of a particular waste is defined by EPA as hazardous, it would be expected that EPA would then list that waste as hazardous, and all such wastes would have to comply with the limited set of regulations identified in 250.46-2, and the complete set of regulations when they are ultimately promulgated (unless a generator demonstrates that his particular waste is not hazardous).

EPA is also charged with establishing legally enforceable standards applicable to generators and transporters of hazardous waste and to hazardous waste management facilities. Facilities which treat, store, or dispose of hazardous waste must have permits, either from EPA or a state hazardous waste program authorized by EPA.

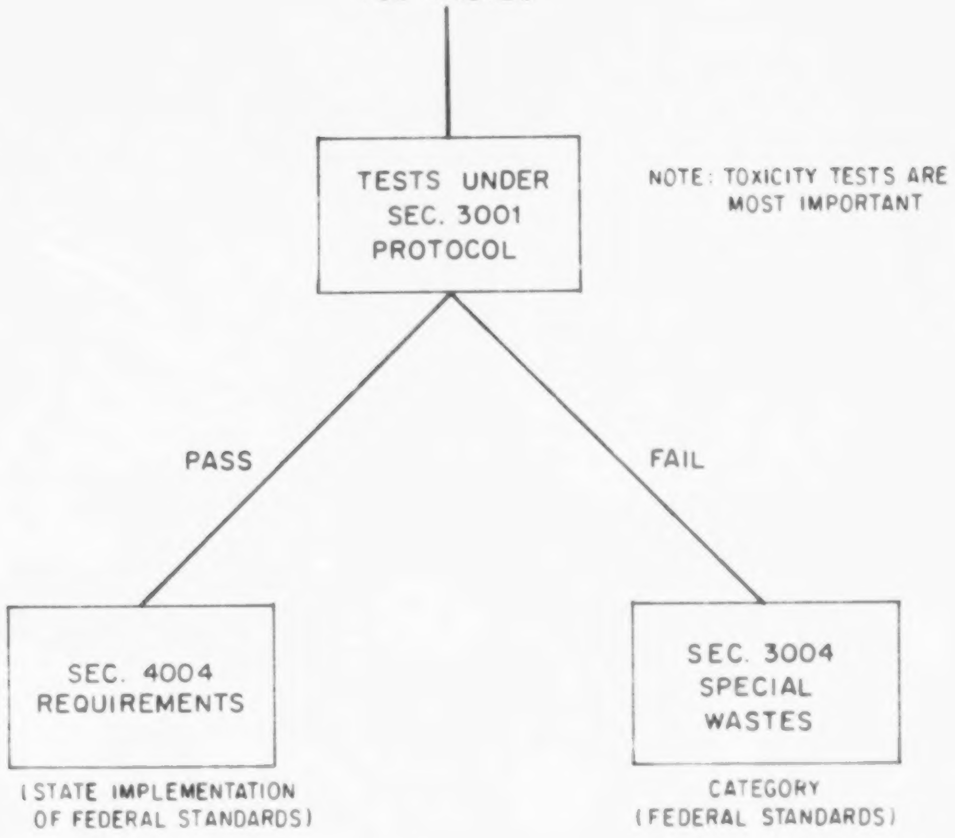
FGC WASTES
TESTS UNDER SEC. 3001 PROTOCOL
NOTE: TOXICITY TESTS ARE MOST IMPORTANT
PASS
FAIL
SEC. 4004 REQUIREMENTS
(STATE IMPLEMENTATION OF FEDERAL STANDARDS)
SEC. 3004 SPECIAL WASTES
CATEGORY (FEDERAL STANDARDS)

Figure 3.2 Regulatory Requirements - RCRA

3.2.1.2 The Act

It is the intent of the act to establish national standards and criteria, but that the individual states would implement and enforce the regulatory program. However, in the event a state does not become authorized to conduct the hazardous waste program in that state, EPA will conduct the hazardous program in that state. Wastes which are identified as hazardous are to be regulated more stringently at the federal level than non-hazardous solid wastes. Where RCRA calls for EPA to establish legally enforceable standards for the management and disposal of hazardous wastes, non-hazardous waste management and disposal is to be regulated by criteria, which are not federally enforceable at least by mechanisms clarified at present. State programs for the management of hazardous waste must be equivalent to the federal program, consistent with federal or state programs in other states, and must provide for adequate enforcement. On the other hand, state plans for solid waste management must meet only certain minimum requirements, including prohibition of open dumps, as defined by EPA and implementation of the federal Management and Disposal criteria, and the establishment of necessary state regulatory powers.

The most important requirement in the area of non-hazardous solid wastes, as it pertains to groundwater contamination from the disposal of FGC wastes, is the prohibition of open dumps.

An open dump is defined in the act by exclusion, as any site where solid waste is disposed of which is neither a sanitary landfill nor a facility for disposal of hazardous waste. A facility qualifies as a sanitary landfill if there is no reasonable probability of adverse effects on health or the environment from disposal of solid waste at the facility. The only action which can be taken by the federal government to encourage state participation and compliance with non-hazardous waste regulations is in the distribution of funds to the states. $11.2 million are appropriated for state solid waste plans for fiscal 1979.

3.2.1.3 RCRA Regulations

The Act is to be administered by the Office of Solid Waste (OSW) of the EPA, and that office is in the process of developing regulations required under the Act. On February 6, 1978, OSW published in the Federal Register proposed rules containing criteria for determining which solid waste disposal facilities shall be classified as sanitary landfills, as defined in the Act. It can be expected that these rules represent the minimum level of control considered acceptable by EPA for FGC waste disposal.

EPA points out the potential for confusion in the use of the term sanitary landfill, which traditionally refers to a practice for the controlled burial of solid wastes, especially municipal wastes, whose primary purpose was disease vector control and for aesthetic value. The definition contained in the Act is much broader, not only in its definition of solid wastes but also in the environmental performance requirements of a sanitary landfill. This is to be accomplished under the proposed rules, by requiring that usable aquifers* not be endangered beyond the property boundaries. Endangerment is defined as the introduction of any physical, chemical, biological, or radiological substance or matter into groundwater in such a concentration that: (1) makes it necessary for a groundwater user to increase treatment of the water (including treatment to meet any maximum contaminant level set forth in any promulgated National Primary

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* an aquifer is "a formation... that contains sufficient saturated permeable material to yield or be capable of yielding significant quantities of water to wells or springs" and is usable as a drinking water source if it contains less than 10,000 mg/l TDS (although states may reclassify aquifers as usable or unusable) defined in proposed regulations for the state underground injection control program, Federal Register, August 31, 1976, by the Office of Water Supply, Use of this definition by the OSW in the administration of RCRA is a good example of coordination of regulatory strategy within EPA.

Drinking Water Standard under the Safe Drinking Water Act), (2) makes it necessary for a future user of the groundwater to use more extensive treatment of the water than would otherwise have been necessary (based on current technology), or (3) otherwise makes the water unfit for human consumption. To assure that usable aquifers are not endangered the proposed criteria specify that one of the two following procedures should be followed:

a. Collection of leachate through artificial liners with subsequent removal, recirculation or treatment; or

b. Control of the migration of leachate by utilizing natural hydrogeologic conditions, or soil attentuation mechanisms. Where appropriate, infiltration of water into the solid waste shall be prevented or minimized.

Furthermore the rules call for monitoring of groundwater, and prediction of leachate migration for as long as leachate may endanger groundwater.

Solid waste disposal facilities shall not be located in the recharge zone of aquifers which are the sole or principal source of drinking water in the area unless no other sites are technologically or economically feasible and the facility is located, designed, constructed, operated, maintained, and monitored to prevent endangerment of the aquifer. These proposed criteria for the classification of solid waste disposal facilities are currently under review by OSW pending final promulgation.

Hazardous Waste

The Office of Solid Waste is currently considering key regulations applicable to owners and operators of hazardous waste management facilities and regarding the criteria for identification of the characteristics of hazardous wastes and the listing of specific hazardous wastes.

There are several key provisions relevant to FGC waste disposal. Under Section 3001 of RCRA, EPA-OSW will define hazardous wastes by two methods:

- Identifying the characteristics of a hazardous waste, and
- Listing specific wastes as hazardous.

For all practical purposes, listed wastes are presumed hazardous unless proven non-hazardous by the generator, while unlisted wastes have to be tested by the generator if he has reason to believe that the waste is hazardous. However, it is difficult to establish what someone "knows or has reason to believe" and this section may be difficult to enforce.

The characteristics of a hazardous waste identified by EPA for immediate regulatory control are ignitability, corrosivity, reactivity, or toxicity of these, the toxicity test is the most critical one with respect to FGC wastes [48]. The toxicity test begins with the Extraction Procedure (EP) which is described in greater detail in Volume 3, and which consists of:

- Filtration or centrifugation, save liquid.
- Grind or hammer* solid residue.
- Extract in water of pH 5 (but, using no more than 4 ml of .5N acetic acid per gram of solid).
- Recombine extract with liquid from Step 1.

A joint ASTM/DOE collaborative test program is also being designed to evaluate leaching procedures.

The waste would be considered hazardous if the extract contains concentrations of any substance in excess of an established threshold. Thresholds have been established for As, Ba, Ca, Cr, Pb, Mg, Se, Ag and certain pesticides based on EPA National Interim Primary Drinking Water Standards. The thresholds have been set at 10 times the drinking water standards. Some tests on FGC wastes using the Extraction Procedure (EP) has been conducted for the EPA by the Oak Ridge National Laboratories (ORNL) [115]. Tests appear to indicate that EP is effective in removing inorganic species but not effective for organics. At least one sample of fly ash seems to pass EP tests [42]. Thus, it is likely that some FGC wastes would be considered hazardous by this criterion.

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*This requirement would have some bearing on the acceptability of treated FGC wastes, where the most beneficial effect of treatment may be the reduction in permeability. If the waste was structurally weak and thus vulnerable to the hammer test, this benefit would be discounted in the evaluation of hazardous characteristics.

Because many FGC wastes have not yet been fully tested and are temporarily considered "special wastes," it is impossible to ascertain whether such wastes will be regulated as hazardous or non-hazardous. If found non-hazardous, the wastes would be regulated under Sections 1008 and 4004 of RCRA. However, if specific wastes are tested and found to have the characteristics of a hazardous waste as stated earlier, a limited subset of disposal procedures will be required as specified in Section 250.46-2 (Utility wastes) of the regulations. (See Figure 3.2.) Utility wastes means fly ash, bottom ash, and FGD sludges generated from steam electric power plants.

All storage and disposal facility operators must provide detailed physical and chemical analysis of each waste stream handled which identifies the hazardous characteristics of the waste, once, when the facility starts handling the waste and periodically thereafter.

New facilities shall not be located in:

- An active fault zone.
- A regulatory floodway (as designated by the Federal Insurance Administration).
- A coastal high hazard area (unless the facility is built so as to be safe from hurricane and tsunami waves),
- a 500 year flood plain (unless built such that the facility will not be inundated by a 500-year flood),
- Wetlands (unless the facility obtains a NPDES permit and a Section 404 permit for dredging or filling),
- A Critical Habitat Area under the Endangered Species Act of 1973 (unless it can be demonstrated that the facility will not jeopardize the continued existence of the endangered and threatened species), and
- The recharge zone of a sole source aquifer (unless located, designed, constructed, operated, and maintained to prevent endangerment of the aquifer).

Security provisions also exist for such sites, including a 6-foot fence surrounding the active disposal areas, and a 200-foot buffer zone requirement.

Generators, transporters, and disposers of hazardous wastes are required to keep a manifest and recordkeeping system.

Post closure care of a hazardous waste facility shall be continued for a maximum of 20 years (less if the owner or operator can demonstrate that such care is not needed). The most significant requirements for post closure care are monitoring for migration of waste constituents and the uncertain financial liabilities associated with potential ultimate disposal requirements.

A groundwater monitoring system of four wells is required (less if there is no potential for discharge to a usable aquifer). One of these wells must be upgradient of the site. Baseline monitoring must be performed for at least 3 months prior to startup of any new facility. The frequency of analysis of groundwater samples varies from one to four times per year depending on groundwater flow rates. A depth of about 1.5 meters (5 feet) from liner bottom to groundwater is required.

If the monitoring indicates that significant contamination has occurred, the operator must notify the EPA, determine the cause and extent of contamination, and discontinue operation until the problem is corrected. Removal of waste, redesign of liner or other engineering and operational corrective actions may be required.

3.2.2 Safe Drinking Water Act/Underground Inspection Control Program

This discussion of the Safe Drinking Water Act is limited to the underground injection control program because this is a potential disposal method for FGC wastes. The Office of Water Supply (OWS) of EPA is to develop regulations for state programs covering the underground injection of wastes via wells for the purpose of protecting groundwater sources of drinking water. EPA has interpreted well injection to include "subsurface emplacement through a bored, drilled, or driven well or through a dug well where the depth is greater than the largest surface dimension, whenever a principal function of the well is the subsurface emplacement of fluids." (September 23, 1977, draft of proposed regulations). EPA must decide which states require an underground injection control program, and has decided to concentrate initially on states in which underground injection is commonplace and groundwater drinking supplies may be endangered, with subsequent regulation nationwide. State programs:

- May authorize underground injection either by permit or rule,
- Must provide for the protection of drinking water sources, and
- Must provide for inspection, monitoring, record keeping, and reporting requirements.

The states have primary authority for enforcement, but if the EPA finds that the state is not enforcing the regulations, EPA assumes enforcement responsibility. Draft proposed regulations (September 23, 1977), define and prohibit endangerment of usable aquifers and require plugging of wells within a radius of endangering influence from the injection well, and generally require procedures to insure that injected wastes will not migrate from the level of injection upward into a usable aquifer. The regulations will not substantially restrain the underground injection of wastes in new wells since they reflect present day best operating practices.

Based on discussions with EPA, Office of Water Supply, and related proposed regulations under SMCRA and RCRA, it appears unlikely that State Underground Injection Control Programs under SDWA will be used to regulate mine disposal of FGC wastes. The Office of Surface Mining apparently intends to regulate these activities under SMCRA, while the RCRA definition of disposal includes injection of wastes. Thus, there are several federal laws which may be interpreted to regulate the injection of FGC wastes in mines. The Office of Water Supply has indicated that it does not intend to regulate this activity under SDWA, and apparently OSM or OSW will regulate this disposal option.

3.2.3 Surface Mining Control and Reclamation Act

The Surface Mining Control and Reclamation Act of 1977 is discussed more extensively below. Only its pertinence to groundwater contamination resulting from FGC waste disposal is discussed here. Among the expressed purposes of SMCRA is to "assure that surface coal mining operations are so conducted as to protect the environment". Throughout the Act, groundwater is specifically identified for protection via permit and reclamation programs.

Reclamation plans must:

- Show consistency with local physical environmental and climatological conditions,
- Contain the results of test borings or other equivalent information showing the location of subsurface water, and
- Contain a detailed description of measures to be taken during the mining and reclamation process to assure the protection of:
  - the quality and quantity of surface and groundwater systems, and
  - rights of present users to such water.

Reclamation operations must be conducted to prevent long term adverse changes in the hydrologic balance. Specifically, this would include changes in water quality and quantity, depth to ground water and changes in the location of surface water during leaching. Applicable state and federal regulations have to be met as well. It is suggested in this standard that water pollution treatment methods can be used but this has to be secondary to reclamation practices that prevent any of the above adverse affects. There is a minimal list of such practices, some of which include lining drainage channels, revegetating, burying and sealing acid-forming, toxic-forming material, etc. The major issue is whether or not using sludge material as fill would prevent meeting these specific requirements of this standard.

Specific detailed requirements are given for sedimentation ponds which must be used to collect all surface drainage from distributed areas due to mining or reclamation until drainage from the disturbed area has met the applicable water quality requirements. The effluent limitations listed in these regulations include maximum allowable and daily average values for iron, manganese, total suspended solids, and pH. These are minimum standards and it is not clear what additional ones might be used or how the Office of Surface Mining might view such standards in terms of disposal of waste materials as fill. It is noted that state and federal regulations also apply.

Any acid or toxic materials must be buried and treated when necessary. Further, water must be removed from contact with such materials. Surface water monitoring is required after reclamation, with the regulatory authority determining the scope and frequency and length of data collection. Backfill materials have to be placed so that adverse affects on ground water flow and quality are minimized. It appears that offsite effects are the ones of concern, although there is no indication of the classification of ground water systems in these regulations as was found in RCRA regulations. Monitoring of ground water levels and infiltration rates is required. Additional standards are included for alluvial valley floors, roads, and permanent impoundments.

Mining operations west of 100° west longitude must not materially damage the quantity or quality of surface and underground water systems in alluvial valley floors. It is not clear whether FGC waste disposal in surface and underground mines will be regulated under SMCRA, RCRA or both.

Another unresolved issue is the potential inconsistency in groundwater protection between SMCRA and SDWA. Regulations promulgated by the Offices of Water Supply and Solid Waste of EPA under SDWA and RCRA have adopted the philosophy of protecting only usable aquifers from "endangerment" (as defined on page 4). The Office of Surface Mining, on the other hand, has written regulations which protect "groundwater systems" from changes in flow and quality, apparently including both usable and unusable aquifers. Resolution of these issues pends further action by the Office of Surface Mining.

3.2.4 State Regulations

The separate States have administrative power over state programs required under RCRA and SDWA, so long as they meet minimum requirements established by EPA. Since it is the intent of OWS not to regulate FGC wastes under this program, the state programs were not reviewed for this study. However, an earlier review revealed that most state programs are inconsistent with the proposed federal program and are understaffed for enforcement. To our knowledge, none of these state programs have considered the regulation of FGC wastes via underground injection.

State solid waste programs are reviewed in greater detail below where the emphasis is on surface water related issues. It is of interest, then, to note that all state solid waste programs reviewed apply equally to surface and groundwaters, via definitions that "waters of the state" include surface and groundwaters.

3.3 Surface Water Related

3.3.1 Introduction

Several unresolved issues dominate the present status of surface-water-related regulations potentially applicable to land-based FGC waste disposal. This is not true for ocean disposal, where relatively well-defined regulations exist for dumping from vessels (under the Marine Protection Research and Sanctuaries Act) for outfall disposal (under the Federal Water Pollution Control Act Amendments of 1972 and 1977), and for artificial reef construction (discussed below). Principal unresolved issues for land disposal are:

- Distinctions between definitions of "point" versus "non-point" sources of water pollution;
- Establishment of a clear hierarchy of regulation integrating the requirements of RCRA, FWPCA, and SMCRA; and
- Response to the remand of EPA's proposed Effluent Guidelines for the utility industry.

The importance of these issues may be made apparent by the following illustrative questions, none of which can be definitively answered at this time.

1. What surface water discharge criteria apply to a landfill of FGC waste on utility plant site?
2. What surface water discharge criteria apply to an impoundment of FGC waste at a location remote from a utility plant?
3. What surface water discharge criteria apply to FGC waste disposal in a surface mine?

If FWPCA considerations for disposal at remote (off-plant) locations requires the development of new types of National Pollutant Discharge

Elimination System (NPDES) permits, the manner in which such permits will be defined for various FGC waste disposal options will be significant. It is not clear which disposal options would be considered "point sources" subject to such permitting, and which, if any, would be considered exempt as "non-point sources". The same issue is further complicated for disposal in surface mines, which, if allowed, might involve independent regulation of drainage from "non-point source" disposal areas by OSM, as well as or in place of "point source" regulation by EPA.

This background of emerging and shifting policies and responsibilities needs to be kept in mind when reviewing the detailed discussions of individual regulations below.

3.3.2 Surface Water Quality Issues from Point Source Discharges

3.3.2.1 Federal Water Pollution Control Act

The Federal Water Pollution Control Act established the NPDES permit program. States may administer their own NPDES program based on EPA determination that the program (a) will ensure compliance with the Act, (b) is authorized under state laws, and (c) provides for adequate enforcement. An NPDES permit is required for any point source discharge into navigable waters. The permit sets maximum permissible effluent levels for specific pollutants which are established on a case-by-case basis (in some cases, however, national Effluent Guidelines apply to various aspects of the NPDES permit). The permittee submits monthly reports of waste water analyses.

Promulgated EPA guidelines covered effluent discharges from various sources within a power plant, including fly ash transport water and cooling tower blowdown, but effluents from FGD systems were not regulated separately. A summary of the regulated parameters is given in Table 3.2. It is important to remember that certain aspects of these guidelines were challenged in litigation and are presently on remand, with revisions reportedly expected in early 1979. This is discussed more fully in Section 4.1.4 of Volume 2.

Table 3.2

Effluent Parameters Subject to Effluent Guidelines Limitations for the Steam Electric Power Generation Category

BAT[1]	Maximum Daily (mg/ℓ)	30-day Average (mg/ℓ)
TSS	100	30
Oil and Grease	20	15
Copper	1	1
Iron	1	1
Free Chlorine	0.5	0.2
BAT		
As above plus		
Phosphorous	5	5

(TSS in rainfall run-off to be limited to a maximum daily of 50 mg/ℓ.)

[1] Not all effluent sources subject to all the parameter limitations. See discussion of remand decision in Section 4.1.4 of Volume 2.

Source: [49]

Copper and iron levels from boiler blowdown were covered but metals in ash transport water were not regulated. BAT regulations, which must be met for all power plants during the period 1984-1987, and New Source Performance Standards, were similar to current BPT regulations, but with the addition of regulation of phosphorous levels. In addition, the regulations limited run-off from material storage and construction to maximum daily TSS of 50 mg/ℓ. Other provisions of FWPCA pertinent to power plants are discussed in Section 4 of Volume 2.

Pollutants Potentially Regulated by Drinking Water Criteria

Data from ten samples of unstabilized FGC waste from eastern and western coal are given in Table 3.3. It shows the constituents obtained from the initial leachate from the base of the pile compared to the corresponding drinking water criteria. All of the elements analyzed and TSS exceeded the drinking water criteria but not by more than a factor of 10, with the exception of TSS. Two samples exceeded the range 5-9 for pH. Limited data showed that barium exceeded the drinking water criterion by a factor of 5, nitrate was at the criteria level and silver was 0.5 times the criteria level. COD in fresh sludge ranged from 40-140 mg/ℓ. It was high for sulfite sludge but this sludge also showed more rapid oxidation, and after one pore volume displacement had a COD of 10 mg/ℓ or less.

Pollutants Not Presently Regulated

The major potential pollutants typical of FGC waste effluents and not presently regulated by effluent guidelines include dissolved solids, (e.g., Ca and SO_4) and trace metals, which can exceed water quality criteria prior to mixing.

Non-Point Source Discharges

Potential environmental problems associated with disposal of FGC wastes by landfill include groundwater and surface water contamination from leaching of dissolved solids and trace metals. Most state regulatory authorities are authorized to protect sub-surface waters but only a few states have specific criteria for groundwater protection. Applicable criteria for Missouri and New York are shown in Tables 3.4A and B. The criteria for TDS are lower than reported concentrations of dissolved solids in leachate from unstabilized FGC waste piles.

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Table 3.3

Comparison of FGC Waste Liquids with Water Criteria

Drinking Water Criteria mg/ℓ	Range of All Samples	Concentration - Criteria (Nondimensional)									
		Sample[a]									
		A	B	C	D	E	F	G	H	I	J
As 0.05	<0.8-2.8	0.6	0.4	2.0	0.04	0.4	1.2	2.8	0.1	0.8	0.2
Cd 0.01	0.4-11	5.0	1.2	0.4	--	11	1.3	--	--	5	2.5
Cr 0.05	0.22-5	5.0	0.8	1.8	--	0.6	0.2	--	--	--	1.1
Pb 0.05	0.2-6.6	0.8	3.0	4.6	<0.2	6.6	0.2	<0.2	<0.2	0.8	<0.1
Hg 0.002	0.03-2.5	2.5	--	--	<0.1	<0.5	<0.001	<0.1	<0.1	0.1	0.03
Se 0.01	0.28-63	10.0	3.3	10.0	4.2	<2	7.8	63	14	2.8	0.3
F 2	<0.5-5	--	0.5	3.3	--	1.7	1	--	--	5	<0.5
TDS[b]	6.6-48.5	36	6.6	30.0	13.4	18.8	20.5	28	18.4	8.4	48.5
pH (actual values)[c]	6.7-12.2	6.7	6.8	8.0	12.2	8.7	8.0	7.8	7.3	10.7	8.9

[a] Sample data are as follows:

Sample	Station	Absorbent	% Ash	Sampling Data
A	Mohave	Limestone	3	Mar 1973
B	Cholla	Limestone	59	Nov 1974
C	Shawnee	Limestone	40	Jun 1974
D	Shawnee	Limestone	6	Jan 1977
E	Shawnee	Lime	40	Jun 1974
F	Shawnee	Lime	6	Sep 1976
G	Shawnee	Lime	6	Oct 1976
H	Shawnee	Gypsum	6	Aug 1977
I	Duquesne Phillips	Lime	60	Jun 1974
J	LGE Paddy's Run	Carbide Lime	12	Jul 1976

[b] Assumed 500.

[c] Primary water supply criteria for most states are in ranges of 6.5 to 8.5 or 5 to 9.

Source: [50]

Table 3.4a

Discharge Criteria in New York and Missouri

State of New York*
Groundwater Contaminant Limits

Substance	Concentration in mg/ℓ	
	Schedule I	Schedule II
Alkyl benzene sulfonate (ABS)	1.5	1.0
Arsenic (As)	0.1	0.05
Barium (Ba)	2.0	1.0
Cadmium (Cd)	0.02	0.01
Carbon chloroform extract residue (CCE)	0.4	0.2
Chloride (Cl)	500	250
Chromium (hexavalent)(Cr+6)	0.10	0.05
Copper (Cu)	0.4	0.2
Cyanide (CN)	0.4	0.2
Fluoride (F)	3.0	1.50
Iron (Fe)	0.6	0.3
Lead (Pb)	0.10	0.05
Manganese (Mn)	0.6	0.3
Nitrate (N)	20.0	10.0
Phenols	0.002	0.001
Selenium (Se)	0.02	0.01
Silver (Ag)	0.10	0.05
Sulfate (SO_4)	500	250
Total dissolved solids	1000	500
Zinc	0.6	0.3
pH**	6.5-8.5	6.5-8.5

---

*New York State Groundwater Classifications and Standards (Part 703).

**When natural groundwaters have a pH outside of range indicated above, the natural pH may be one extreme of the allowable range.

State of Missouri*
Groundwater Contaminant Limits

Contaminant	Maximum Value Allowed
Arsenic	50 μg/ℓ
Barium	1,000 μg/ℓ
Cadmium	30 μg/ℓ
Chromium (Total)	500 μg/ℓ
Copper	20 μg/ℓ
Cyanide	10 μg/ℓ
Fluoride	1,200 μg/ℓ
Lead	50 μg/ℓ
Nickel	800 μg/ℓ
Phenols	5 μg/ℓ
Selenium	10 μg/ℓ
Silver	50 μg/ℓ
Zinc	100 μg/ℓ
COD	10 μg/ℓ
Threshold Odor Number (TON)	3
Linear Alkylate Sulfonates	1.0 mg/ℓ
Chlorides	250 mg/ℓ
Sulfates	250 mg/ℓ
Total Dissolved Solids	500 mg/ℓ
Nitrate as (NO_3)	10 mg/ℓ

Heavy Metal Ratio shall not exceed 1.00:

$$\frac{Cu}{20} + \frac{Zn}{100} + \frac{Pb}{50} + \frac{Cr}{500} + \frac{Cd}{30} + \frac{Ni}{800} = 1.00$$

Where the abbreviation for the metal in the fraction is the measured concentration in the effluent in micrograms per liter (μg/ℓ).

---

*Missouri Groundwater Recharge and Irrigation Return Water (Appendix III).

Table 3.4B

National Interim Primary Drinking Water Regulations Maximum Contaminant Levels for Inorganic Chemicals[*]

Contaminant	Level (mg/ℓ)
Arsenic	0.05
Barium	1
Cadmium	0.010
Chromium	0.05
Fluoride	**
Lead	0.05
Mercury	0.002
Nitrate (as N)	10.
Selenium	0.01
Silver	0.05

---

[*] Federal Register, p 59570, December 24, 1975.

[**] Fluoride is regulated as a function of average daily maximum air temperature:

Air Temperature (°C)	Fluoride Level (mg/ℓ)
12.0	2.4
12.1-14.6	2.2
14.7-17.6	2.0
17.7-21.4	1.8
21.5-26.2	1.6
26.3-32.5	1.4

3.3.2.2 Surface Mining Control and Reclamation Act Promulgated Interim Enforcement Provisions

The "Surface Mining Control and Reclamation Act" was passed in August of 1977. Resultant interim regulations have been in effect since December 1977. The proposed permanent regulatory program was published in September 1978, with final regulations expected in 1979.

The interim standards issued for reclamation requirements as a result of SMCRA include protection of surface water. It is at present unclear how these performance standards will be applied to a situation where FGC waste material is disposed of in a mine. The Office of Surface Mining in the Department of Interior has indicated that it will develop a position on this issue during 1979. For the present, it is assumed that requirements of standards for reclamation would have to be met if FGC wastes were disposed of in mines.

The interim regulatory program requires that all surface drainage be passed through one or more sedimentation ponds. This would produce a point source discharge. The regulations require that such discharges meet applicable state and federal laws, but at a minimum must meet the following effluent limitations[1]:

Effluent Characteristic	Maximum Allowable	Average of Daily Values for 30 Consecutive Discharge Day
Iron, total	7.0 mg/ℓ	3.5 mg/ℓ
Manganese, total	4.0 mg/ℓ	2.0 mg/ℓ
Total suspended solids	70.0 mg/ℓ	35.0 mg/ℓ
pH	within the range of 6.0 to 9.0	--

Treatment must be used if limitations are not met (although sedimentation ponds can be a form of treatment). For a number of the mountain and western states, total suspended solids will be determined on a case-by-case basis, and the limitations for this parameter are somewhat more restrictive.

---

[1] Adapted from "Surface Mining, Reclamation and Enforcement Provisions," Dept. of the Interior, Office of Surface Mining Reclamation and Enforcement, Dec. 13, 1977.

The commentary process on these regulations indicated that EPA may have more stringent limitations under FWPCA, which would have to be met. In addition, the limitation for manganese in the interim program is applicable only to acid drainage [51]. This change was based on the fact that there was reported to be insufficient data to justify limitations on manganese in alkaline waters.

For underground operations, similar effluent limitations apply to discharge from sedimentation ponds. In addition, any discharge from areas disturbed by underground or surface mining, must meet state and federal regulations and the effluent limitations established in these standards. It is not clear how disposal of FGC wastes in deep mines will be viewed as this issue is not explicitly covered by the interim regulations. For the present, it is assumed by the authors that such disposal would be permitted provided all regulatory standards for water, etc. could be met. In particular, the regulations establish particular measures to prevent water pollution from mine drainage, which include:

- Diverting water from underground workings,
- Preventing water contact with toxic-forming materials and minimizing contact time with waste (as defined by SMCRA regulations), and
- Maintaining barriers to enhance post-mining inundation and sealing.

It would appear that these measures, at least the first two, would make disposal of non-mining wastes more acceptable.

Proposed Permanent Regulatory Program

The proposed regulation promulgated on September 18, 1978 for the permanent regulatory program under the Surface Mining Control and Reclamation Act have several important changes over the draft form of these regulations that were circulated in July 1978. One key difference concerns the "discharge water into underground mines." Under the draft regulations, the following requirements were stipulated:

"The regulatory authority may approve the discharge of water into abandoned mine voids when the water is used as an integral component of any operation conducted for the purpose of water disposal, fire extinguishment, or subsidence control, and provided that

(1) the hydrology of the ground or surface water approximate to the disposal area is not affected,

(2) the mine water pool remains essentially static,

(3) such water is treated for any and all pollutants if it is discharged on the surface, and

(4) introduction of water into the voids is acceptable when all other geologic factors have been considered.

The source of water shall be designated prior to its mixture and injection, and any and all affects on the hydrology and geology of the subjacent as well as superjacent strata shall be specified."

This section changed substantially in the September 18th publication.

"Surface water shall not be diverted into underground mine workings unless the person who conducts the surface mining activities demonstrates to the satisfaction of the regulatory authority that the diversion will--

(a) abate water pollution or otherwise eliminate public hazards resulting from underground mining; and

(b) be discharged as a controlled flow meeting the water quality requirements of Section 816.52 for pH and total suspended solids except that the total suspended solid concentration may be exceeded only if the suspended material is approved by the regulatory authority or is limited to--

 (2) fly ash from a coal-fired facility;

 (4) flue gas desulfurization sludge;

(c) the discharge will not cause, result in, or contribute to a violation of applicable water quality standards;

(d) minimize disturbance to the hydrologic balance."

(*Section 816.55, Surface Mining and Reclamation Operations*, proposed rules for permanent regulatory program.)

This is one means by which the Office of Surface Mining could control underground injection of materials into underground mines in lieu of EPA regulations of similar types of land disposal.

The discussion accompanying these proposed rules is interesting in that comments are made on the development of the water quality standards of the Surface Mining Control and Reclamation Act. The following are quotes from this discussion (Federal Register, Volume 43, No. 181, pages 41744-41745):

> "In developing these standards, an alternative considered by the drafters in response to public comment was to do no more than incorporate by the reference EPA's Effluent Guidelines and Standards for the Coal Mining Point Source Category under the National Pollution Discharge Elimination System Permits Program. This alternative was analyzed and rejected for several reasons.
>
> "First, the proposed effluent limitations would be applied throughout the entire phase of surface coal mining and reclamation operations, as required for the protection for the hydrologic balance . . . whereas EPA's effluent limitations regulations apply only to the active phase of mining operations . . .
>
> "A second reason why this alternative is not being adopted is that U.S. EPA's regulations apply only to existing point source discharges of water from mining operations and do not apply to non-point source discharges . . .
>
> "The third reason why the use of EPA's regulations alone is believed to be insufficient is that these regulations do not apply at all to discharges of ground water."

3.3.2.3 Surface Water Quality Issues Related to Runoff: Issues Defined By Existing and Emerging Regulations

RCRA

Regulations under Section 3004, concerning standards applicable to owners and operators of hazardous waste treatment storage and disposal facilitites have been proposed by EPA (December 18, 1978). Priority issues relating to surface water contamination by runoff from hazardous waste treatment, storage, and disposal facilities (which are addressed by the standards) include site selection, design, monitoring, and closure of such facilities.

The legislation requires the integration of RCRA with existing regulations to the maximum extent practicable. Hence, it is expected that the performance standards established by the regulations under Section 3004 will interface with the point source permitting authority NPDES established under the Federal Water Pollution Control Act (FWPCA) (PL 92-500).

An important consideration with respect to the regulations under this section concerns discharges to surface waters other than navigable waters. Proposed regulations under RCRA reference the NPDES (permit) regulations under FWPCA which are applicable only to point source discharges to navigable waters, which is not a restriction on RCRA jurisdiction. Controversy may arise over any expansion of the NPDES permit program beyond the jurisdiction of FWPCA. A related area of concern may be the integration of RCRA with existing federal legislation emphasizing other water quality considerations (e.g., the Safe Drinking Water Act).

It appears likely the facility siting considerations will be given an emphasis under the regulations for Section 3004. Such siting considerations may be viewed primarily in terms of land use (i.e., location with respect to residences, roads, etc.) and safety (location with respect to active faults). However, there may also be consideration of issues critical to surface run off in the site selection criteria. In particular, the location and design of facilities which may be subject to "worst case" run off situations (i.e., flood conditions) may be of particular concern with respect to the treatment, storage, and disposal of hazardous wastes.

Without proper maintenance or monitoring, surface runoff and other discharges from closed facilities may continue to affect water quality long after the operations of such facilities have ceased. The proposed RCRA regulations address this problem within the context of Section 3004. The Legislative requirements for continuity of ownership and financial responsibility may be utilized to require owners to make provision for monitoring and maintenance of closed facilities, as well as insuring that such facilities are closed in a safe manner consistent with the public helath and environmental safety.

Specific requirements for monitoring of surface waters, emphasizing waters on site, are required with respect to the determination of contamination. Visual inspections are also likely to be required, to insure that maintenance operations are effective in the prevention of unanticipated hazards or discharges.

The December 18, 1978, proposed regulations [8] pursuant to Section 3004 temporarily exempt FGC wastes from hazardous waste disposal procedure standards, including those which address the control of runoff and leachate. The regulations classify FGC wastes as "special" to be subject to further rulemaking at some point in the future. The regulations imply that some, but not all, FGC wastes may be subject to the disposal requirements for hazardous wastes on a case-by-case basis if tests do warrant.

Effluent Related Issues of Proposed Federal Regulations

Effluent related issues considered within the context of RCRA may be viewed in terms of the classification of material as having either a hazardous or non-hazardous nature. Hazardous materials will fall under the jurisdiction of Federal regulations. Certain components of a waste which are considered particularly hazardous may receive special attention in regulations. Such components include boron, molybdenum, selenium, which are often present inf FGC waste, but which are likely to be prohibited for disposal via landfarming when present in waste material. Other components which could receive special attention in the regulation with reference to landfill as a disposal option include cyanide, arsenic, chromium, and other heavy metals.

Effluent from the treatment or processing of wastes, particularly hazardous wastes, could be classified as constituting a hazard to health and the environment, and therefore, controlled under the regulatory provisions for the various disposal options under Section 3004 (subject, of course, to the criteria established for the determination of hazardous waste under Section 3001).

State Programs Under RCRA

Subtitle D of RCRA is entitled "State or Regional Solid Waste Plans." Among the objectives of the subtitle are to provide for federal guidelines for state solid waste disposal plans; establish procedures for development and implementation for such plans; and provide for federal assistance to the states for activities such as facilities studies, technology assessments, legal expenses, etc., in connection with the planning effort and the implementation of programs.

The criteria for determining which solid waste disposal facilities pose no reasonable probability of adverse effects on health or the environment (Federal Register, February 6, 1978) through degradation of surface waters include the compliance of point source discharges (including collected surface runoff) with the National Pollutant Discharge Elimination System (NPDES) permits issued under Section 402 of the FWPCA amendments. Additional criteria include the control of non-point source discharges (including surface runoff) to prevent or minimize such discharges into any off-site surface water.

The objectives of thr RCRA "non-hazardous" waste landfill surface water criteria are to assist in attaining the objectives of the FWPCA. The permit requirements under Section 402 of that Act provide the method for the regulation of point source discharges which may have adverse affects on surface waters. The criteria provide for additional controls on non-point source discharges, to the extent that such discharges be "prevented or minimized." To comply with these requirements, non-point source discharges can be collected, by channeling into a ditch or trench, and regulated as point-source discharges. Collection of non-point sources (i.e., surface leachate, leachate seepage, and including surface runoff) creates a point source, which is required to comply with the NPDES permit if discharged to off-site surface waters. These criteria under RCRA thus deal with both point and non-point source discharges from solid waste disposal facilities by deferring to the FWPCA with respect to the former; and by establishing criteria for the states to use in regulating the latter, which, in effect, require that the discharges, including surface runoff, be considered as a point source. Thus, most discharges from solid waste disposal facilities can be subject to the requirements of the NPDES permit.

In total, the proposed criteria are interpreted to comply with the requirements of Section 1008 (a) (3), which authorize guidelines "..... to provide minimum criteria to be used by the states to define those solid waste management practices which constitute the open dumping of solid waste or hazardous waste....." The criteria in addition suggest guidelines under Section 1008 (a) (2c), providing for the ".....protection of surface waters from runoff through compliance with effluent limitations under the FWPCA, as amended....."

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3.4.1 Present Status

The states are at various stages in regulating and planning for the management and disposal of solid wastes. Presented are brief descriptions of the legislative and regulatory requirements of selected states which have been suggested by EPA staff at regional and national levels to be relatively advanced on the issues of solid waste management and disposal. Table 3.5 lists the states whose solid waste regulations are discussed in the subsequent pages of this report.

Region I: Maine

Solid waste management regulations were promulgated under Title 38, Maine revised statutes, Section 1304, and became effective in February 1976. Chapter IV of the regulations addresses land disposal options. Section 406.1 specifies that a solid waste disposal site boundary shall not lie closer than 300 feet to a classified body of water, nor closer than 1,000 feet to a potable water supply. The Department of Environmental Protection deems these buffer zones to be sufficient to protect surface water. Other requirements to protect surface water include moderate slope (i.e.. less than 15%) and "good design and operation." Sites not meeting the site characteristics criteria may be approved if "... good design and operation can be shown to provide adequate protection to surface ... water resources."

One element of design which the Department will review is the diversion of surface waters away from the proposed disposal site. Drainage systems will also be reviewed before any plan is approved.

The determination of whether or not a waste is hazardous will be made by the Department on request. The state apparently does not have a hazardous waste management program at present. The requirements of RCRA are expected to be incorporated into the solid waste management

Table 3.5

Management and Disposal of Solid Wastes in States

Federal Region	State[1] Whose Regulations are Discussed
I	Maine
II	New Jersey
III	Pennsylvania
IV	Tennessee
V	Illinois
VI	Texas
VII	Kansas
VIII	California
IX	Oregon

[1] The states listed were chosen for illustrative purposes. All 150 States are at various stages of planning or implementing management of solid waste disposal operations.

plan now being drafted; and are expected to substantiate and reinforce the states existing regulations. Hazardous wastes in the state are likely to be more stringently controlled in the state as RCRA Subtitle C regulations are promulgated and become effective.

Region II: New Jersey

The New Jersey Solid Waste Management Act was passed in 1970; important amendments to the Act were passed subsequently, including Chapter 326, passed in 1975. The Act and its amendments address solid waste management planning in the state and issues concerning collection and disposal of solid waste.

For planning purposes, each of the 21 counties in the state and the Hackensack Meadowlands District was designated a solid waste management district. Two groups of districts are required to have plans completed by early 1979; the third group of districts must complete plans by mid 1979. Plans are required to cover a ten year period and are to be updated every two years.

With respect to hazardous wastes, the legislation requires monitoring wells to be installed at any site accepting hazardous or chemical wastes, bulk liquids or pesticides. Discontinued acceptance of the waste and implementation of "an acceptable system of interception, collection, and treatment" is required if analyses indicate a hazard or potential threat to water quality. The legislation also requires interception, collection, and treatment of all leachate generated at a solid waste facility. The effective date of the regulation is set at 1980.

The regulations prohibit any new sanitary landfill to be constructed where solid waste is or would be in contact with surface or groundwaters. A similar provision applies to existing landfills. The impairment or further degradation of surface or groundwaters as a result of solid waste disposal activity or leachlate generation is prohibited. Ground water monitoring is required of new facilities.

The only specific mention of by-products resulting from air pollution control devices was in the context of the disposal of incinerator residues.

The New Jersey definition of hazardous waste is broad and bears similarity to the legislative definition in RCRA. There is citation of the definitions of toxicity determined under the Occupational Safety and Health Act, and hazardous materials classification of the Department of Transportation. RCRA, however, post-dated the legislation and is not cited.

The New Jersey legislation is considered to have anticipated the requirements of RCRA in some respects, including the designation of planning districts and the development of solid waste management plans. New Jersey also requires a manifest system for tracking of hazardous wastes. Reduced incidence of ocean dumping is expected to result in increased emphasis on land-based disposal in this densely populated state.

Region III: Pennsylvania

The Commonwealth is in the process of revising the state solid waste management plan. The Solid Waste Management Act was passed in 1968 as Act 241. Regulations under the Act are found in Chapter 75 (Solid Waste Management Rules and Regulations).

The planning process is addressed in Subchapter B of Chapter 75. Solid waste management planning in the Commonwealth is initiated at the level of the municipalities. Subchapter C addresses permit and standards for disposal facilities. The design criteria for sanitary landfills address the issue of surface water contamination through set-back requirements (25 feet) and requirement for the management of surface water. In addition, "the site shall be designed and operated in a manner which will prevent surface water percolation into the solid waste material deposits." Section 75.37(e) addresses surface water management techniques for the standards for fly ash, bottom ash or slag disposal areas. The provision may be appropriate to FGG wastes as they may include fly ash. Surface runoff from "adjacent areas should be diverted away from flyash on slag disposal piles (s)...(and) run-off shall not be allowed to discharge freely onto the slopes of the fill." In addition to these requirements for control of runoff, it may be necessary to provide "contingency plans for treatment of run-off from the fill..."

Section 75.38 addresses general standards for industrial and hazardous waste disposal sites. The definition of hazardous waste in the context of these regulations is similar to that set forth in RCRA. To date, the Department of Environmental Resources has reportedly not had adverse reactions to its enforcement of the regulation with respect to hazardous waste. Specific reference to possible surface water contamination by runoff with the context of the design and operating requirements of this section are limited.

Region IV: Tennessee

This state only recently passed solid waste management legislation, but is reported by EPA staff to be further along than other states in the region. The legislation incorporates elements similar to those specified in RCRA, including a manifest system for hazardous wastes and an inventory of open dumps. Regulations under the law may be delayed until critical issues are resolved at the federal level, including the determination of what constitutes a hazardous waste. As the regulatory process proceeds, problems with respect to on-site disposal options and regulation of hazardous wastes are considered possible. Hazardous waste criteria and a listing of hazardous wastes are required by the legislation.

The criteria under consideration for determining whether a waste is hazardous are very similar to the criteria under consideration by EPA, as authorized by Section 3001 of RCRA. It is expected that the Tennessee regulations will closely parallel the federal regulations under that section for most classifications (e.g., reactivity, toxicity).

Detailed studies of disposal site hydrologic characteristics may be required under the state regulations, prior to the approval of a disposal site. Issues to be examined with respect to surface water in location and design studies include: site location and drainage relationships with contiguous areas; proximity to surface streams and potential for flooding; and seasonal variation in water quality, evaluated for a number of parameters. Site specific criteria under consideration for the evaluation of disposal sites address issues related to surface runoff. Surface runoff from contiguous areas is expected to be controlled and not allowed to enter a disposal or a landfarm site. Moreover, location and design of a site is unlikely to be approved if the possibility of degradation of surface waters attributable to the site exists. Special precautions are likely to be instituted to prevent exposure of a site to flood waters. Federal regulations under RCRA Section 3004 may also be utilized in the evaluation of disposal and landfarm sites. The performance standards under that section may also be applied by the State of Tennessee to hazardous waste storage, treatment, and disposal facilities. Other criteria and standards may also be used if demonstrated to be equivalent to the federal standards.

Region V: Illinois

The Illinois Environmental Protection Act (Illinois revised statutes, Chapter 111 1/2, 1001-1051) establishes the authority of the Illinois Pollution Control Board (the Board) to adopt regulations which are, in effect, consistent with the purposes of the RCRA (e.g., the prohibition against and/or regulatory control of open dumping). Under Title V, Sections 21 and 22, the Board has authority to set design and performance standards for "refuse collection and disposal sites and facilities," where refuse is broadly defined to include garbage and other discarded materials. In addition, the Board has authority to set standards for handling, storing, processing, transporting and disposal of hazardous refuse. Hazardous refuse, in the context of the Illinois legislation, is defined as "refuse with inherent properties which make such refuse difficult or dangerous to manage by normal means, including chemicals, explosives, pathological wastes and wastes likely to cause fire." Significantly, the definition of hazardous waste in this section of the Illinois legislation emphasizes primarily the inherent difficulty in management as the fundamental criterion for the determination of hazard, rather than the danger posed to the health of those exposed to the waste.

Title III, Sections 11 and 12 of the Illinois Environmental Protection Act address issues of water pollution in the state. Section 12(a) prohibits "the discharge of any contaminants into the environment in any state so as to cause or tend to cause water pollution in Illinois"; while Section 12(d) proscribes the "deposit (of) any contaminants upon the land in such manner so as to create a water pollution hazard...." Taken together, these paragraphs may be interpreted to prohibit the disposal of any "contaminants" on the land if such disposal endangers surface or ground waters, and may also be interpreted to prohibit unregulated surface runoff from a waste disposal site, if such runoff could result in the contamination of surface or ground waters.

In fact, the Illinois Pollution Control Board regulations state "no person shall cause or allow the development or operation of a sanitary landfill unless the applicant proves to the satisfaction of the agency that no danger or hazard will result to the waters of the state because of the development and operation of the sanitary landfill." While the rule does not specifically address the issue of surface runoff from a landfill site, runoff which does constitute a hazard to surface or ground waters could be interpreted to violate the intent of the rule. Rule 313 prohibits the discharge of contaminants into the environment so as to cause, or tend to cause, water pollution, placing regulatory authority behind the legislative intent of Title III, Section 12(a) (see above).

Hazardous or liquid wastes and sludges may be accepted at a sanitary landfill, if authorized by permit, under rule 310, which regulates disposal of Chapter 7, Part III, "special wastes." Thus, the possibility of FGC wastes being disposed of at sanitary landfill sites in Illinois exists, with such disposal being regulated within the context of Chapter 7.

Regulations addressing the transportation of special wastes are expected to be proposed by the Board. The primary focus of the regulations is anticipated to be on the issuance of permits to special waste haulers; to provide procedures for the inspection of numbering of vehicles, tanks and drums; and to require the legal hauling of special wastes to approved disposal, storage, and treatment sites. It is significant that pollution control residuals may be considered a sub-classification of special wastes but any person hauling only coal combustion fly ash may be exempted from the permit requirements of the regulations. The wording of this possible exemption may be critical, since admixtures of FGC sludge with fly ash may not meet the criteria for the permit exemption.

It is of interest to note that the maintenance and submittal of operating records required by Rule 317 apparently include the submittal, four times per year, of water monitoring data (e.g., comprehensive analysis of water samples from on site and nearby wells and surface waters). Thus, the Board is able to monitor whether water quality standards have been violated by operation of landfill. It is also of interest to note that a hazardous waste disposal site in the state was ordered closed by a circuit court judge in 1978, due to possible ground water contamination. The order to close, which also required removal of wastes and contaminated soil, was termed "landmark" by the state's Attorney General's Office.

Region VI: Texas

Solid waste regulations for the state of Texas were promulgated under the Texas Solid Waste Disposal Act of 1969, as amended. The Texas Departments of Health and Water Resources are jointly responsible for implementation and enforcement of regulations authorized by the act. The Office of Solid Waste Management of the Department of Health is primarily responsible for the management of municipal solid wastes; industrial solid wastes fall within the jurisdiction of the Department of Water Resources. The protection of surface waters are among the criteria considered in site selection and facility design. In particular, the criteria stipulate the control of surface drainage on a land disposal site to "minimize surface water runoff onto, within, and off the working area." This control is to be affected by "dikes, embankments, drainage structures and diversion channels of adequate size and grade...to control surface water." Special requirements are also in effect with respect to protection of a site from 50- and 100-year frequency floods.

Operational requirements for most conventinal landfill sites include the following:

"1. Solid waste shall not be placed in unconfined waters which are subject to free movement on the surface....
2. The site shall be protected from flooding by any nearby streams with suitable levels....
3. Suitable water diversion methods shall be provided to divert the flow of uncontaminated runoff or other surface water away from the active disposal area.
4. Rainfall runoff within the landfill area that has been contaminated by solid waste on other polluted waters shall not be discharged from the site unless the site operation...is authorized by the Texas Water Quality Board."

There is a provision in the regulations for the disposal of other sludges "only if special provisions are made and approved by the Department." No definitions or examples of "other sludges" are provided, and it is unclear what the term "other sludges" may include. Department approval is also required for disposal of hazardous waste.

Region VII: Kansas

The Kansas Solid Waste Management Act addresses first the organization and planning of solid waste management in the state. The act also focuses on permit requirements for the construction, alteration or operation of a solid or hazardous waste processing facility on disposal areas. The conditions of the permit are authorized to be designed so as to "protect human health and the environment and to conserve (the disposal or processing) site." The Secretary of the Department of Health and Environment has statutory authority to approve the types and quantities of solid waste allowable for processing or disposal at a permitted authority.

"Dumping or disposal of any solid or hazardous waste onto the surface of the ground, or into the waters of the state" is deemed unlawful without having obtained a permit. A condition for issuance of a permit includes departmental approval for the installation and operation of environmental quality monitoring systems, including monitoring wells.

The standards for disposal sites addressed in the revisions of the regulations are expected to require that "surface runoff and leachate seeps shall be controlled so as to minimize non-point source discharges into surface waters." Specifications for such control are not detailed in the revisions to the regulations.

Hazardous wastes are defined in Section 64-3402 (Kansas Solid Waste Managment Act) as solid wastes which, because of quantity, concentration, or physical, chemical or infectious characteristics, pose a hazard to the environment or are dangerous to human health if improperly managed. As in the Illinois statutes, the technique of management, in addition to inherent characteristics of the waste, is considered to contribute to a substantial present or potential hazard. Significantly, the revisions to the standards for management of solid waste are application to (a) waste which consists of or contain hazardous wastes; and (b) any mixture formed by combining any waste or substance with a hazardous waste (emphasis added). The regulations might thus be interpreted as applicable to FGC wastes, which include trace metal species which may be viewed as hazardous. The burden of proof as to whether a waste containing components with hazardous properties listed by the Department, but the criteria are still being developed.

Industrial wastes, i.e., those wastes not suitable for discharge to a sanitary sewer and treatment plant, may not be disposed of without a disposal authorization by the department.

Location, design and operation guidelines will be developed by the department. The standards for hazardous waste disposal area (facility closure) require the covering of cells with an impervious layer to minimize leachate and contaminated runoff. Maintenance of land disposal areas after closure will include treatment of contaminated runoff.

The Kansas regulations incorporate many of the requirements of RCRA, including the local solid waste management plans; manifests, and reporting requirements; and standards applicable to generators, treatment and disposal facility operators and transporters. The regulations discussed here will be implemented on a temporary basis pending legislative review in 1979.

Region VIII: California

The California Solid Waste Managment and Resource Recovery Act of 1972 and the Hazardous Waste Control Act are the two fundamental statutes relevant to the disposal of solid and hazardous wastes in the state. The Solid Waste Management Board (Board) and Department of Public Health (Department) are the two state agencies with primary responsibility for, respectively, solid and hazardous wastes.

The Board has authority in the legislation to formulate and adopt minimum standards for solid waste management to protect air, water and land from pollution. Standards addressed include the location, design, operation, maintenance and ultimate reuse of solid waste processing and disposal facilities. The Board must also review compliance of local solid waste management plants with state policy (plans are to be reviewed every three years).

The Board also retains permitting authority for the operation of solid waste facilities. The operation of such facilities without a permit is prohibited.

The conditions of the permit are not specified in the legislation. Determination of whether FGC wastes would be permitted for disposal at a solid waste disposal site has not been made by the Board, and would depend on an analysis of the physical and chemical characteristics of the waste. A finding that the waste is hazardous would place its disposal within the jurisdiction of the Department of Public Health. The Department is authorized by legislation to make a listing of hazardous wastes, and regulation criteria and guidelines for the identification of hazardous and extremely hazardous wastes. The Department also sets minimum standards for operating procedures, including handling, processing, use, storage and disposal of hazardous wastes. In addition, the Department sets standards for the use and operation of hazardous waste facilities.

The legislation is specifically concerned with the protection of public health and safety and that of domestic and wild life. To this extent, though not explicitly, the legislation addresses the degradation of surface water quality by runoff.

Region IX: Oregon

Solid waste regulations for the State of Oregon were authorized under Chapter 459 and subsequent amendments. Hazardous wastes are specifically addressed in Section 459.410-690 of the statute. The regulations contained in the Oregon administrative rules pertaining to solid waste management are likely to be revised and expanded during 1978. The new rules, however, have not been proposed by the Department of Environmental Quality (DEQ) at the time of this writing. Hence, the discussion will focus on the old rules presently in force. In addition, current rules pertaining to the management of environmentally hazardous wastes are expected to be completely revised during early 1979. It should be recognized that the regulatory requirements in the State of Oregon with respect to the management of solid and environmentally hazardous wastes may be significantly altered before 1980. How the revised regulations will be influenced by the developing regulatory framework authorized at the federal level under RCRA is yet undetermined. In certain respects, Oregon is considered to have progressed quite far in the management of environmentally hazardous waste. The state reportedly has the only licensed and regulated hazardous waste disposal site in operation west of the rockies. Environmentally hazardous waste disposal sites are licensed and regulated under Chapter 340, Section 6, Subdivisions 2 and 3 of the Ohio administrative rules. Subdivision 2 specifies the procedures for issuance, denial, modification and revocation of licenses for the disposal of environmentally hazardous wastes. Subdivision 3 establishes "requirements for environmentally hazardous waste management from the point of waste generation to the point of ultimate disposition..." and addresses the classification and declassification of environmental hazardous wastes. The general requirements of the subdivision bear similarity to certain requirements of RCRA, such as the maintenance and reporting of records. Waste classified as environmentally hazardous include pesticide and radioactive wastes (no disposal sites for radioactive wastes can be established, operated, or licensed in the state). The statutes make specific provision for the establishment of a chemical waste disposal site in the state, and provide for its regulation by DEQ (see above).

3.4.2 State Responses to December 18, 1978, Proposed Regulations Under RCRA

In December, 1978, EPA published proposed regulations under Subtitle C of the Resource Conservation and Recovery Act (RCRA). The specific proposals concerned: "(1) the criteria for identifying and listing hazardous wastes, identification methods and a hazardous waste list; (2) standards applicable to generators of such waste for record keeping, labeling, containerizing and using a transport manifest; and (3) performance standards for hazardous waste management facilities." The proposed criteria and standards are likely to effect pre-existing state-level hazardous waste management regulations and programs, and to influence the form of such regulations and programs in those states which have not yet enacted hazardous waste legislation comparable to RCRA.

Tennessee

State hazardous waste regulations are still in draft form, incorporating changes based on recent public hearings. Latest draft is dated November, 1978. After consideration of all public comments, further changes may be made before regulations are finalized.

The November draft is reported to be similar to EPA's proposed regulations for hazardous waste. With respect to fly ash bottom ash, and other air pollution control wastes, the likelihood is that these wastes will be considered as special cases. Such wastes are deemed to be of relatively low hazard, but will be generated in sufficiently high volume to merit special consideration. The state is trying to recognize these kinds of wastes. "Utility wastes" are not defined in the Tennessee list of hazardous wastes, as they are in the proposed federal regulations pursuant to RCRA. However, fly ash, bottom ash, and scrubber sludges are specifically identified as potentially hazardous.

The state intends to pursue federal funding although the test will be whether the regulations as promulgated will be sufficiently stringent to qualify.

Pennsylvania

The State Department of Environmental Resources, Office of Solid Wastes (OSW) anticipates that some changes will be forthcoming in the Pennsylvania solid waste management regulations as a result of EPA's proposed Subtitle C regulations. However, the changes in the Pennsylvania regulations are as yet undeveloped, and it is too early to say what form those changes may take.

The Pennsylvania solid waste program is not yet completely approved for acceptance as a state solid waste management program. The OSW will most likely pursue federal approval and funding. The recommendations of the OSW in this matter have apparently not yet been acted on by the Secretary of the Department or the Governor. The response to the Subtitle C proposed regulations may have some bearing on the decision to pursue, and timing for obtaining federal approval.

Utility wastes are now categorized as a solid (not hazardous) waste, and are disposed at approved sites. Perhaps because of the existence of apparently effective regulations and disposal sites, wastes generated by coal-fired electric utilities are not now considered to be a problem in the state.

Florida

Existing environmental legislation in the state has designated an Office of Hazardous Waste (OHW) under the Department of Environmental Regulation. The present hazardous waste program is based on the case-by-case determination of the hazardous nature of waste material. If a waste is found to be hazardous, the legislation requires that the waste be rendered innocuous and/or disposed of in a manner approved by the Department.

The OHW and Department are proposing comprehensive hazardous waste legislation in the next legislative session. Similar legislation was proposed by the Department in the previous session, but was not acted on by the legislature. To date, the proposed legislation has no sponsor, and it appears premature to estimate chances for, or timing of, enactment.

In its present form, OHW staff perceive the proposed legislation to be comparable to RCRA definitions of, and criteria for, hazardous wastes. It appears to be the intent of the Department to be independent, in the sense of formulating legislation and regulations which address problems peculiar to Florida. However, it appears likely, if the proposed program is adopted, that the state will attempt to respond to federal guidelines for hazardous waste under the solid waste management progam and hence pursue federal funding.

It also appears likely that the state will adopt a position similar to EPA, in the matter of special case wastes, e.g., utility (and in Florida, gypsum) wastes. In its proposed form, the Florida Act is broad enough to provide for interim, or special case, status for such wastes.

North Dakota

The basic plan of the state at this time is to assume administrative responsibility of the Federal Hazardous Waste Program in North Dakota. Enabling legislation has been passed, but the state presently has no program. The legislation is vague, and there is no provision for civil penalties. Utility wastes are now handled on a case-by-case basis. There are five or six major power plants in the state; hence, utility wastes are and will be a major concern. The solid waste office is working with the state geological survey in studying disposal options and also formulating responses to the federal proposal. The state solid waste office does not anticipate a significant problem from the disposal of fly ash and bottom ash, but does anticipate a potential problem in the disposal of scrubber sludges.

Site specific criteria are and will be an important factor in authorized disposal of these wastes.

North Dakota will pursue federal funding of its program, if in fact the federal program is adopted. Adoption and implementation could take one to two years, depending on when the federal program is finalized.

Illinois

The proposed EPA regulations were considered by the Division of Land and Noise (the state agency with solid waste management responsibility) to be more stringent than existing Illinois regulations. A specific example of this federal stringency was noted with respect to the heavy metals. Thus, for the hazardous waste criteria, there is a likelihood that the state will incorporate elements of the federal program. Changes may also be forthcoming with respect to state standards for hazardous waste generators and management facilities.

The position of the state regarding control of special wastes, (i.e., utility wastes) is apparently still unclear because of a question of whether such wastes are, in fact, hazardous. Illinois regulations are now compatible with certain requirements of the special waste standards (i.e., the manifest system). Enabling legislation under which other requirements could be met is on the books.

3.5 Ocean Disposal Related

3.5.1 Statutory Base

The Marine Protection Research and Sanctuaries Act of 1972 (PL92-532) is the basis for all domestic regulation of ocean dumping from vessels. Several major provisions of this legislation are discussed below. Disposal in the ocean via outfalls is regulated as a point source under the NPDES permit program under the FWPCA.

Policy

Section 2(b) of the Act states,

> "The Congress declares that it is the policy of the United States to regulate the dumping of all types of materials into ocean waters and to prevent or strictly limit the dumping into ocean waters of any material that would adversely affect human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities."

Mandatory Considerations in the Issuance of Permits

The Act states that no dumping may take place without a permit from the Administrator of the EPA. Section 102(a) conditions the issuance of such permits upon determination by the Administrator that, "...such dumping will not unreasonably degrade or endanger human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities." The specific review criteria to be used in reaching these determinations are prescribed as follows:

"(A) The need for the proposed dumping.

(B) The effect of such dumping on human health and welfare, including economic, aesthetic, and recreational values.

(C) The effect of such dumping on fisheries resources, plankton, fish, shellfish, wildlife, shore lines and beaches.

(D) The effect of such dumping on marine ecosystems, particularly with respect to -

  (i) the transfer, concentration, and dispersion of such material and its byproducts through biological, physical and chemical processes,

  (ii) potential changes in marine ecosystem diversity, productivity, and stability, and

  (iii) species and community population dynamics.

(E) The persistence and permanence of the effects of the dumping.

(F) The effect of dumping particular volumes and concentrations of such materials.

(G) Appropriate locations and methods of disposal or recycling, including land-based alternatives and the probable impact of requiring use of such alternative locations or methods upon considerations affecting the public interest.

(H) The effect on alternate uses of oceans, such as scientific study, fishing, and other living resource exploitation, and nonliving resource exploitation.

(I) In designating recommended sites, the Administrator shall utilize wherever feasible locations beyond the edge of the Continental Shelf."

Penalties

Section 105 of the Act provides for civil penalties of up to $50,000 for each violation of the Act. It further provides for criminal penalties of not more than one year imprisonment, $50,000 fine, or both. Both the government and private citizens are provided the opportunity to obtain injunctive relief by Section 105 of the Act.

Preemption of Other Jurisdictions

Section 106(d) of the Act precludes state, interstate, or regional authorities from adopting or enforcing any rules or regulations relating to ocean dumping. States may propose ocean dumping criteria to the EPA Administrator who may adopt them if he wishes. Thus, unlike the regulatory climate surrounding land disposal alternatives, ocean disposal of FGC wastes by vessels is the direct responsibility of only one agency, the Federal EPA.

Establishment of Regulations

Section 108 of the Act gives the Administrator the authority to establish such regulations as he deems appropriate. The existing and possible future regulations are discussed below.

3.5.2 Administrative Regulations

Ocean dumping regulations were first promulgated by the EPA in October 1973 to become 40 CFR 220-227. Subsequent amendments were adopted during 1974 and 1977. Two sections of the ocean dumping regulations are particularly relevant to the subject of this report. These are sections 227 and 228 which, respectively, cover the criteria for the evaluation of permit applications for ocean dumping and the need for ocean dumping (227) and the criteria for the management of disposal sites for ocean dumping (220). Part 228 was added to the regulations in 1977, and major changes to Part 227 took place during this same time frame. Changes in the following aspects of the regulations are discussed below:

- Alternatives;
- Prohibited materials;
- Other factors limiting permissible concentrations;
- Monitoring requirements;
- Outfalls; and
- Artificial reefs.

3.5.3 Consideration of Alternatives

As of the 1977 amendments of the regulations, ocean dumping permit applicants must demonstrate that there is no feasible alternative to dumping. The following factors are included in determinations of the need for ocean dumping versus available options:

need for ocean dumping versus available options:

- degree of available treatment of the waste;
- available raw material and process changes;
- relative environmental impact and cost of ocean dumping and other alternatives, including but not limited to landfill, well injection, recycling, additional treatment, and storage; and
- irreversible or irretrievable consequences of the use of alternatives to ocean disposal.

Determinations of the cost feasibility of available alternatives to ocean disposal do not require that costs be competitive and take into account environmental benefits as well.

3.5.4 Prohibited Materials

Under regulations in existence prior to 1977, eastern FGC wastes could have been precluded from ocean disposal entirely on the basis of the cadmium content of the solid phase of many of the materials containing fly ash. This is because absolute limits existed on cadmium and mercury concentrations in both the solid and liquid phases of all materials. These limits were, for mercury, 1.5 ppm in the liquid phase of the waste and 0.75 ppm in the solid phase; and for cadmium, 3.0 ppm in the liquid phase and 0.6 ppm in the solid phase.

Mercury and cadmium are no longer listed as prohibited materials in the new regulations. This is perhaps the single most important change in the regulations with respect to FGC wastes. These substances are now listed as constituents prohibited as other than "trace contaminants", with a new set of interim and anticipated ultimate means of determining whether the "trace contaminant" definition applies. The current criterion for mercury in the liquid phase of the wastes to be dumped in the ocean is as follows:

> "...mercury concentrations in the disposal site, after allowance for initial mixing, may exceed the average normal ambient concentrations of mercury in ocean waters at or near the dumping site which would be present in the absence of dumping, by not more than 50%..."

A complementary criterion to be applied to all wastes, including FGC wastes, is a series of bioassay tests. The object of these tests is the identification of both acute and chronic toxicological impact potentials of the waste and the potential for bioaccumulation of toxicants in marine organisms as the result of exposure to the waste. The regulations indicate that bioassay procedures for suspended particulate and solid phases of waste materials are not sufficiently well developed to mandate the use of such tests as a prerequisite for permit approval. Thus, in the interim, while such procedures are being developed, the EPA personnel responsible for the administration of ocean disposal programs (usually at the regional level) are given a number of options for application review. With respect to mercury and cadmium in the suspended particulate and solid phases of wastes, the interim guidance is as follows.

Mercury and its compounds may be present in the solid phase of a material in concentrations less than 0.75 mg/kg or less than 50% greater than the average total mercury content in natural sediments of similar characteristics at the disposal site. Cadmium and its compounds in solid phase may be present in concentrations less than 0.6 mg/kg or, as with mercury, less than 50% greater than the total cadmium content of the natural sediments of similar characteristics at the disposal site. While these numerical limits are identical to those in the previous regulation, the wide range in "natural" sediment concentrations of mercury and cadmium at disposal sites would ensure considerably greater flexibility than the previous regulations.

3.5.5 Other Factors Limiting Permissible Concentrations

The 1977 amendments to the regulation changed the "mixing zone" concept of previous regulations defining a "release zone" as a cylinder whose outline is 100 meters from the perimeter of the conveyance engaged in dumping.

In the mixing zone, no parameter may exceed .01 of a concentration shown to be toxic to appropriate sensitive marine organisms over a 4-hour period. Field data, mathematical modeling, or theoretical turbulent diffusion relationships may be employed to determine the limits of the area of said toxicity. When no other means are feasible, it may be assumed for purposes of calculation that the waste is evenly distributed through the release zone over the upper 20 meters. These amendments all provide greater flexibility in the permit process.

3.5.6 Monitoring Requirements

The new regulations contain a section 228 devoted to disposal site management, including monitoring requirements and requirements for the evaluation of the environmental impacts of disposal activity. A major change in agency philosophy is reflected in these requirements. Previously, it appeared that permit applicants might be responsible for baseline and trend assessment monitoring at disposal sites. However, Part 228 clearly spells out that these responsibilities belong to the federal government. Applicants' responsibilities are now confined to special monitoring programs designed case by case to determine short-term impacts of disposal activities.

Another important part of the regulation is the establishment of criteria for the evaluation of disposal impacts. In summary, these criteria establish a category of impacts (Category I) which, if identified at a disposal site, requires the EPA management authority to place limitations on use of the site to reduce impacts to acceptable levels. These Category I impacts include:

- statistically significant decrease in populations of valuable commercial or recreational species or species essential to the propagation of valuable commercial or recreational species;
- significant impairment of major uses of the site or adjacent areas due to accumulations of solid waste material;
- adverse effects on taste or odor of valuable commercial or recreational species as a result of disposal activities; or
- identification on a consistent basis of toxic concentrations of any toxic waste, waste constituent or byproduct at levels above normal ambient values outside the disposal site more than four hours after disposal.

These criteria leave open the possibility for accumulations of toxic contaminants within the disposal site to a sufficient degree to impair later harvest of transient (e.g., pelagic) species passing through the site and becoming subsequently available through the food chain to man. Because of the nature of finfish movements and, to a lesser extent, the movements of other valued species (e.g., lobsters), there is a strong likelihood that it would be impossible to detect consistently a direct link between toxic accumulations in a disposal site and organisms passing through that site, as required by the criteria.

3.6 Stability Related

3.6.1 Resource Conservation and Recovery Act of 1976 (PL94-580)

As discussed throughout this report, a key consideration under RCRA is the identification of a waste as hazardous by EPA, Office of Solid Waste. To date, FGC wastes have not been identified as hazardous, and OSW has announced its intent to place whatever portion of these wastes is declared to be hazardous in a special category subject to a limited set of hazardous waste requirements. With respect to physical stability, FGC wastes may constitute a potential hazard to personnel during disposal operations due to liquefaction and loss of structural strength. As such, this would be a concern of the Occupational Safety and Health Administration although they may work closely with EPA to establish protective measures, which may include treatment, moisture content control, and control of waste disposition within the landfill.

Other considerations for the stability of FGC wastes are stated in two regulations published in the Solid Waste Disposal Regulations and Guidelines (40 CFR 241); for completed sanitary landfills (§241.203-2(c): (1) that the integrity of the final cover shall not be disturbed by agricultural cultivation, and (2) the recommendation that major structures are not constructed on the site. Major structures built near a completed land disposal site require design approval by a professional engineer. (This regulation was written in response to the problem of gas production from municipal and domestic wastes, not physical stability of FGC wastes. However, it may be applied to the latter as well.) The possibilities of liquefaction and slumping of FGD sludges placed in fills are significant, and either one could cause a threat to personnel safety or land quality.

The owner or operator of a landfill may screen the wastes to be used in the fill by their exclusion in the permit. The criteria used in determining the acceptability of the waste are the hydrogeology, the chemical and biological nature of the wastes, environmental and health effects, and personnel safety (§241.201-1).

Specific approval by the responsible state authority for sludges with a free moisture content is required because they are a "special waste" (§241.201-2). Because complete dewatering of FGC wastes may not be feasible, this approval implies that states will review most landfill permits for sites planning to dispose of FGC wastes. The guidelines state that the surface and side slopes of all landfills are to be specified in the permit procedure to promote runoff without erosion and to minimize infiltration (§241.204-3(a)). All fill material is to be compacted to the smallest practicable volume (§241.210-1). Inclusion of FGC wastes, which may settle, slump or liquefy, may very well cause alterations in completed surface contour, slopes and runoff and drainage patterns. Compaction of wastes may induce liquefaction of sludges, thereby endangering personnel during disposal operations.

In a brief survey of the solid waste disposal regulations of several states, the following criteria emerged. In Pennsylvania, FGD sludges may be included with fly and bottom ash and slag in landfills if approved by the Department of Environmental Resources (§75.37). This state requires maintenance as long as necessary after completion of the landfill to prevent health or pollution hazards or nuisances, to repair cracks, fissures, slumps and slides, etc. In Illinois, the owner/operator shall monitor and abate gas, water or settling problems within three years of closure of the landfill. Most of the state regulations surveyed do not mention FGC wastes by name, nor do they specify maintenance of final contour of the landfill following completion.

3.6.2 Surface Mining Control and Reclamation Act of 1977 (PL95-87)

The main objective of this statute is to protect the health and safety of the public and to minimize damage to the environment. Section 515 establishes Environmental Performance Standards which set the "approximate original contour" as a goal to aid in restoration of land quality. Regulations promulgated as of this writing include the interim program published in the Federal Register on December 13, 1977, and a permanent regulatory program proposed September 18, 1978 (Federal Register). Key issues which are as yet unresolved: Can FGC wastes be incorporated as backfill material during reclamation operations at surface mines? If so, will they be classified as a "toxic-forming waste" (or hazardous material) or as an "acid-forming material" if high in sulfur compounds.

Backfill materials referred to in the regulations are limited to spoil, overburden and coal processing wastes. In §715.14(3) the use of wastes from other activities outside the permit area is covered but the wording is unspecific as to the types of wastes that would be permissible; §817.20(c), which deals with coal processing wastes, defines "materials from other operations" to exclude non-mining activities.

If future regulations are promulgated which allow the incorporation of FGC wastes in backfilled areas of reclaimed surface mines, interim regulations contain provisions which would have a direct bearing on physical stability, especially those which deal with achievement of land quality functions; specifically:

§784.19	Subsidence Control Plans which "shall describe the subsidence control to be used to achieve compliance with the requirements of subchapter K (Environmental Performance Standards)."
§715.14(J) (3)	"Before waste materials...from other activities outside the permit area...are used for fill material, it must be demonstrated to the regulatory authority by hydrogeologic means and chemical and physical analyses that use of these materials will not... cause instability in the backfilled area.

§715.14(b)	Deals with the situation where modification of the original slope has been approved by the regulatory authority. "The permittee shall...be required to (ii) backfill and grade to the most moderate slope... as is necessary to insure stability."
§715.17(J)	Covers mining in alluvial valley floors west of the hundredth meridian west longitude. "Surface coal mining operations conducted in or adjacent to all valley floors shall...preserve the essential hydrologic functions... The characteristics...to be considered include: (v) configuration and stability of the land surface in the flood plain and adjacent low terraces in alluvial valley floors as they allow or facilitate irrigation of the flood waters or subirrigation and maintaining erosional equilibrium; (vi) moisture holding capacity of the soils within the alluvial valley floors and physical and chemical characteristics of the subsoils which provide for sustained growth or cover through dry months."

The case of acid- or toxic-forming waste materials as defined in §710.5 is dealt with in §715.14(j)(1):

> "Any acid-forming, toxic-forming or combustible materials identified by the regulatory authority that are exposed, used or produced during mining shall be covered with a minimum of four feet of non-toxic and noncombustible materials...(2) Backfill materials shall be selectively placed and compacted wherever necessary... to ensure the stability of the backfill materials."

This requirement also applies in §717.14, the backfilling and grading of road cuts, mine entry area cuts, and other surface work areas.

Section 716.7(e)(4) covers the case of reclamation of prime agricultural land which is under the jurisdiction of the Department of Agriculture. Given the present uncertain status of FGC wastes with regard to their hazardous nature, it is probable that the Department of Agriculture would prohibit the use of such materials in any manner in such designated areas (SCS Engineers, 1977).

An additional stability consideration is stated in §784.15, Dams and Impoundments, subsection (b)(x): "Slope stability analyses will be required for existing and proposed embankment slopes for construction and long-term conditions... Consideration must be given to the possibility of landslides into the impoundment..." Another regulation which deals with impoundments, which are often used to contain FGC sludges, is §715.18(a): "No waste material shall be used in or impounded by existing or new dams without the approval of the regulatory authority." This regulation is followed by extensive construction requirements which include periodic inspections of dams and impoundments.

If FGC wastes are determined to be legitimate backfill materials, then the major restrictions in their use will be compliance with the above-mentioned regulations and also with performance standards aimed at achieving the "approximate original contour." Subsidence, whether through liquefaction or consolidation, may cause violations of the contour requirement over time, and the threat of landslides may be realized if proper restrictions and guidelines are not developed. At present, the regulatory program does not address this issue although the foundation has been laid to implement the use of FGC wastes in mine reclamation.

3.6.3 Federal Coal Mine Health and Safety Act of 1969 (PL91-173)

This statute focuses primarily on miner safety while on the mine property, with respect to disease and safety. Accident prevention is stressed; for example, storage of materials, usage of equipment, mining engineering, and air quality. The latter include such accidents as gas build-up, explosions and the cumulative health effects of inhalation of fugitive dust and other particulates (e.g., black lung).

The disposal scenarios described in Section 2 involve disposal in an abandoned portion of an underground mine behind an engineered bulkhead. Therefore underground mining disposal of FGC wastes is not an occupational safety issue for miners if performed correctly.

3.6.4 Occupational Safety and Health Act of 1970 (PL91-596)

The prime responsibility of OSHA covers worker safety, as does the CMHSA. In 1974, a memorandum of understanding was published between MESA and OSHA (Federal Register, July 26, 1974) which established the exclusive authority of the former on mine property. OSHA jurisdiction extends to the storage and handling of materials at power plant sites and at landfills. There are safety problems in these circumstances where FGC wastes are used to support a load (e.g., in a landfill cell) which could endanger personnel if loss of structural strength occurred. Liquefaction during materials storage is not dangerous unless the regaining wall (embankment or container) fails and personnel may be flooded. Because liquefied sludges may flow almost as fast as water, this could be a hazard. During transportation, vibrations may cause liquefaction and generate noticeable volumes of interstitial waters. The OSHA regulation 29CFR 1910.176(d) calls for the provision of "proper drainage" during storage and handling but not during transportation. OSHA would have authority over the reclamation of abandoned mines because no mining activities are taking place, therefore, the workers would not be subject to MESA authority.

3.6.5 Dam Inspection Act of 1972 (PL92-367)

This statute calls for the inspection of all non-federal dams over 25 feet in height, and impounding, at maximum water storage elevations, at least 50 acre-feet. A national inventory, conducted by the Corps. of Engineers [52], included "approximately 49,000 dams, most of which were privately owned. Of these, approximately 9,000 were identified as high-hazard, meaning in the event of a failure, there would be substantial loss of life and property". An announcement of the Federal Program for Inspection of Non-Federal Dams was announced by the White House in December 1977, and funds were appropriated for the inspection of the 9,000 high-hazard dams. Findings of each inspection are written up and the report is sent to the owner/operator of the dam or impoundment and to the governor of the state with recommendations as to the safety of the dam. It appears that any impoundment meeting the height and capacity criteria, which is located in a high-hazard area, as defined above, would be inspected regardless of the material it contained.

3.7 Land Use Related

3.7.1 Overview

From the broadest perspective, the key impact issues concerning land use are those directly related to the regulation of the location, operation and final disposition of land-based disposal sites. The Resource Conservation and Recovery Act of 1976 is the principal legislation governing land disposal of waste material.

The classification of FGC wastes remains a focal issue because of the implications this classification poses for site selection, operation and closure, Furthermore, while speculative at this time, the designation of two types of solid wastes by RCRA may ultimately alter the manner in which some local governments control the location of waste disposal sites within their jurisdiction. These issues will be addressed in the specific discussion of RCRA-related regulation.

The Surface Mining Control and Reclamation Act of 1977 is important because coal mines represent a disposal option. Further, this legislation was designed to regulate certain types of land use. As discussed below, the degree to which specific regulation promulgated as a result of this Act apply to FGC waste disposal, is not totally clear.

From conversations with OSM and background materials included with various regulations, it seems likely that EPA and OSM may attempt coordination of efforts on land disposal of waste material. The draft and/or untried nature of most regulatory programs that can be directed at solid waste disposal confuses a number of issues, as noted below.

3.7.2 "Resource Conservation and Recovery Act of 1976", Associated Proposed Regulations, and State and Local Regulations

As discussed in 6.2.2, the key regulatory issue surrounding the land disposal* of FGC wastes due to the Resource Conservation and Recovery

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*"Disposal" as defined in RCRA includes: "...the discharge, deposit, injection dumping, spilling, or placing of any solid waste into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including groundwaters."

Act is the ultimate designation of these sludges as "hazardous" or "non-hazardous." The discussion below ignores this issue other than to address the requirements for disposal under either designation.

3.7.1.1 "Standards Applicable to Owners and Operators of Hazardous Waste Treatment and Disposal Facilities" (Proposed December 18, 1978)

RCRA provides ultimate federal regulatory authority over hazardous waste disposal, although states may administer federally approved programs. Key land use issues indicated by the proposed standards were derived from discussions of:

- General site selection,
- Technical requirements for closure and long-term care,
- Landfills,
- Surface impoundments,
- Basins, and
- Landfarms.

Overall, there are significant financial liability provisions and closure costs to ensure environmentally sound disposal of wastes. Key elements of the issues listed above are:

General Site Selection - Most of the mandatory standards are concerned with removal from and avoidance of public areas and environmentally sensitive areas. These latter include wetlands, permafrost areas, critical habitats, etc. with some excepted cases.

Closure and Long Term Care - This section makes mandatory the requirement that the closed site land is "amenable to some productive use." Closure procedures must insure that waste cannot be contacted by human or animal life and that discharges of waste harmful to health or the environment do not occur. The type of cover (e.g., one that minimizes or eliminates infiltration of water, supports vegetation, prevent sublimation, etc.) is one such requirement. For landfills or other sites where waste remain, future use cannot include residential, agricultural, or other use which could disturb the "integrity" of the closed site.

Landfills, Surface Impoundments, and Basins - These must be located and operated to prevent direct contact with surface water, and the borders of the site must be at least 150 meters from a water supply. The landfill must be at least 1.5 meters above the historically high water table. These requirements place constraints on location of sites and thus may be considered land use issues.

This discussion has only highlighted specific requirements of the standards for disposal of hazardous materials. Should some FGC wastes be designated hazardous, the main land use issue appears to be whether or not sufficient facilities can be found for the traditional disposal of the volumes anticipated. One question is how the designation "hazardous" will affect the location of sites. In some parts of the country, there is difficulty in locating sites even for the disposal of municipal refuse. In more highly congested areas, traditional dumps have often been located at or near less desirable development land (e.g., wetlands). There is also the economic question of what increase in cost the specific new requirements represent, and how much of an impact that would have on operators, especially those in the private sector. It would seen that this would compound the site location difficulties and problems of waste volume. These are in addition to specific issues raised by the legal requirements listed above.

3.7.2.2 "Criteria for Classification of Solid Waste Disposal Facilities" (Proposed February 6, 1978)

Proposed "Criteria for Classification of Solid Waste Disposal Facilities" were published in February 1978 while the final criteria have not been published to date. The criteria listed must be followed for the location, design, construction, operation, completion, and maintenance of disposal facilities if they are to be classified as posing "... no reasonable probability of adverse effects on health, safety, or the environment."

Key land use issues covered by these criteria include protection of environmentally sensitive areas, such as wetlands, critical habitats, permafrost regions, and sole source aquifers. Restrictions relevant to land applications of waste material prevent spread of disease and contamination and ensure safety. The major issue for the disposal of non-hazardous materials is the eventual adoption by all the states of these or similarly protective criteria. In Section 3.3 state existing regulatory programs are reviewed, all of which were developed prior to RCRA criteria or guidelines.

3.7.2.3 Title 40, Part 256 - "Guidelines for Development and Implementation of State Solid Waste Management Plans"

The guidelines for approval of state plans are still in draft form, thus a number of changes could occur before the final guidelines are published. A key issue can be identified from these draft guidelines and the discussion of EPA's interpretation of their intent (included as background with the draft). First of all, it is noted that while it is not the intent of the guidelines to supplant private sector initiatives in solid waste disposal, some state initiatives mav also be needed. This appears, in part, as a recognition of the difficulty in locating disposal sites in some regions. The EPA (in the discussion preceeding the guidelines) recognizes the local or regional role in site selction and/or acquisition. However, it is an explicit intent that states explore options for more direct control over siting and facility development. Of particular interest is the following quotation (page 23 of the draft):

> "EPA invites comment on methods for the state to obtain greater control over facility acquisition. Such methods could include obtaining the authority to override local zoning laws or to contract directly for facilities and services requiring facility permits to conform to regional plans developed under the state plan, or instituting a public utility agency to regulate the supply of services."

It is difficult to predict the outcome of such suggested control. While sufficient sites for disposal remains a very important issue, it does not appear that it can be dealt with other than to recognize its significance and to follow the progress of state plan development.

An additional issue was noted in EPA's interpretation of the intent of these guidelines. It suggests coordination with the Department of the Interior for an inventory of mining wastes which would include abandoned lands. It is suggested that this coordination might also increase the use of sludges (unspecified) in reclamation of abandoned mining lands, noting that DOI will provide states with funding for reclamation once they have approved enforcement programs for activating sites. It appears that OSW and the DOI are considering abandoned locations for the disposal of sludge (with possible financial support).

3.7.2.4 State and Local Issues

It is evident that state solid waste plans will probably undergo at least some modification in those states applying for EPA approval in light to the final guidelines established by RCRA. The degree of modification will depend on the differences between existing state plans and interpretation of the requirements established by federal criteria and guidelines (and yet to be finalized).

Location of land disposal sites, as a land use issue, is typically a decision left to local prerogatives. Where zoning exists, landfills can be included as "conditional uses" making them subject to review by some municipal authority, while, in some cases, "garbage dumping" or even open dumping is prohibited. Many local communities also have performance standards: usually a general list prohibiting uses that produce noxious odors, noise, air pollution, water pollution, etc., (sometimes at a specific level) with the determination of compliance left to some municipal authority. Where sanitary landfills are included as a conditional use, local requirements concerning buffer zones and access, as well as final cover and reclamation may also be listed. These can be in addition to existing state permitting requirements or regulations where the latter exist.

As with other levels of disposal regulation, the major issue surrounding local regulation of landfall sites is the local availability of sufficient sites for the land disposal of FGC Wastes. With site designation left under local control, local citizen pressure, competition from other more lucrative land uses, historical precedent or practices, and land availability could all be important. Evolving state authority over the location of sufficient disposal capacity for the state, if implemented, could alter the significance of this issue somewhat, but this would represent a new role for state government. Furthermore, it would appear that designation of FGC wastes as hazardous would compound the problem from the standpoint of local acceptance as well as the earlier mentioned economic standpoint.

3.7.3 Surface Mining Control and Reclamation Act of 1977 and Associated Regulations

The Surface Mining Control and Reclamation Act is relevant because surface and underground mines are being considered as options for FGC waste disposal. SMCRA can be viewed as a land use law -- in essence, it is directed toward preventing practices that (in addition to posing a threat to human health) degrade environmental quality. It establishes, for most situations, requirements for reclamation of mined land to its pre-mining capabilities. The Act itself does not prohibit or allow for the disposal of wastes generated by other than mining practices. For the purpose of identifying land use impact issues related to this law, it is assumed by the authors of this report that disposal of sludge wastes in surface or underground mines would have to meet the objectives of the Act and the requirements of specific regulations.

The Act includes performance standards which provide the framework for promulgation of a minimum set of regulations. Interim regulations are presently in effect and the permanent regulatory program was proposed on September 18, 1978, Federal Register. The standards include operational procedures that are directed toward the protecton of surface and groundwater quality and quantity, and control of erosion and air pollution. They are also directed at reclamation procedures that, in addition to providing the above protection and/or control, are aimed at returning mined land to a condition capable of supporting the pre-mining or "better" use.

The term "wastes," without modifiers, is not defined in the Act. There are a number of performance standards that could, if interpreted literally, be applied directly to a number of disposal options for FGC sludges in or at the site of surface or underground mines. These include:

- The stabilization of all surface areas affected by reclamation to effectively control erosion, and air and water pollution;
- The treatment, burial, and compaction or other form of disposal of other debris, acid forming materials and toxic materials* in a manner that would prevent contamination of ground or surface waters; and
- The surface disposal of wastes in waste areas (other than excavations) only when they can and will be stabilized and revegetated.

If the feasibility of sludge disposal in surface or underground mines is assumed, the implications of the following standards (reflecting objectives) should be considered:

- The approximate original contour of the disturbed land must be restored (with exceptions) and stability ensured.
- The reclaimed area must be revegetated with a diverse permanent vegetative cover of the same seasonal variety native to the area (there are alternate use exceptions).

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*Two definitions of toxic materials are found in the Surface Mining Enforcement Provisions.

"Toxic-forming materials means earth materials or wastes which, if acted upon by air, water, weathering, or microbiological processes, are likely to produce chemical or physical conditions in soils or water that are detrimental to biota or uses of water."

"Toxic-mine drainage means water that is discharged from active or abandoned mines and other areas affected by coal mining operations and which contains a substance which through chemical action or physical effects is likely to kill, injure, or impair biota commonly present in the area that might be exposed to it."

- For "prime agricultural" lands, if replaced top soil horizons are altered, they must be equally or more favorable for plant growth/productivity (compared to local "reference" areas). There are also special restrictions for mining (and reclamation) in alluvial valley floors.
- Acid or other toxic drainage to surface or groundwater systems must be avoided by treatment of drainage or of preventing contact with toxic materials.

Interestingly, it appears that the standards for permanent water impoundments, if interpreted literally, could include the ponding type disposal option for FGC wastes.

As part of the permitting requirements, mining operators must prepare mining and reclamation plans that outline procedures to be taken for compliance with this law. In addition, a performance bond must be posted as insurance against non-compliance. The implications of sludge waste disposal in adding risks (if any) to the operator, especially where acid mine drainage is not a problem, are not clear. It would appear that problems arising from this additional liability could range from simple procedural ones, to rejection of sludge disposal by the operator. Discussion with the OSM has indicated that they believe the operator would remain liable although positions on waste disposal in general have not yet been established.

3.7.3.1 Interim Regulations - Final Form

The interim regulatory program defines "wastes" restricting that term to "earth materials" associated with the coal mining/cleaning process. This would, therefore, not include FGC material. However, a single overall statement does encompass disposal of materials other than the defined wastes, this would allow for the use of FGC wastes as fill under the following provision:

> that it "...must be demonstrated to the regulatory authority by hydrogeological means and chemical and physical analyses that use of these materials will not adversely affect water quality, water flow and vegetation; will not present hazards to public health and safety and will not cause instability in the backfilled area." (715.14(j))

In conversation with OSM, it was indicated that the above quoted overall statement was included as an "umbrella" to cover contingencies not yet fully considered. The indication was that a series of "position papers" would follow after the full regulatory program is in effect.

The interim enforcement provisions, now in effect, provide performance standards for both mining operations and reclamation. Below is a brief outline of reclamation performance standards which would appear to be most directly applicable to disposal of sludge material in surface or underground mines. It must be emphasized that OSM apparently intends to evaluate, establish, and clarify their position on requirements related to such disposal at a later date. Thus, the applicability of some standards remains unclear.

1. Post-Mining Use of Land. Disturbed areas must be restored to a condition capable of supporting pre-mining use; or "higher or better" uses where the proposed alternative, among other requirements, is designed to conform with applicable standards for adequate stability, drainage, vegetative cover, and will not pose any actual or probable threat to waterflow reduction or pollution. The main issue here is whether or not disposal of FGC wastes would have an affect on the standards.

2. Backfilling and Grading. All spoil material must be backfilled and compacted where it is necessary to ensure stability, or to prevent leaching of toxic material, and then graded. There are also specific requirements for grading of slopes (with exceptions for high and low overburden ratios. The latter may need to be considered for FGC waste disposal). Several additional standards are included in this section:

(a) Permanent Impoundments. Impoundments may not be constructed on top of areas where excess materials are disposed. It is yet unclear whether or not this would include "sludge as fill" material, although later in this section it requires that all toxic materials have to be covered so that there is no leaching, etc.

(b) Covering Coal and Acid-Forming, Toxic-Forming, Combustible, and Other Waste Materials. All material remaining after mining that might be toxic-forming, etc., must be covered by a minimum of four feet of non-toxic, non-combustible material. It necessary, such material has to be treated to neutralize the toxicity in order to prevent water pollution or to minimize adverse affects on plant growth, land use, etc. In addition, the standards require the toxic forming material shall not be buried or stored near a drainage course so that it would pose a threat of water pollution.

(c) Stabilization. Backfilled materials have to be either placed or compacted (if necessary) to prevent the leaching of toxic-forming materials into surface or ground waters.

(d) Use of Waste Materials as Fill. This paragraph was cited in the discussion above as being the statement that covered the use of wastes other than mining wastes as fill, provided it could be demonstrated that no adverse affects would occur. It is this overall statement that is pending further definition by the Office of Surface Mining.

3. Disposal of Spoil and Waste Materials in Areas Other than Mine Workings or Excavations. There are specific requirements for how spoil materials or waste materials are to be disposed of. However, it is not clear that these could apply to wastes other than mining wastes. These requirements are specifically ones for ensuring stability and prevention of leachate to subsurface waters, etc. Evidently, additional standards for this type of waste disposal are included in the draft regulations that have not yet been received in-house.

4. Revegetation. The major requirement of this section is that vegetative cover will be able to stabilize surfaces and prevent erosion. In addition, revegative cover must be diverse, permanent, and of species native to the area. These standards are general with special ones applied

to prime agricultural land. In the latter case, there are very specific requirements for top soil handling, etc.

There is an entire section of special performance standards for such situations as prime farmland, mountain top removal, etc. Most of these are operational requirements and as they are special situations, it is not clear how much, if at all, they would apply to FGC waste disposal. It is questioned whether prime farmlands could be considered at all.

There is also a section of underground mining performance standards. A review of this section indicates that standards are very similar to those listed above for surface mining. These standards are directed at surface operations for underground mines, and additional standards are forthcoming. The standards do include covering of toxic-forming materials and backfilling and grading, protection with hydraulic systems, etc.

In summary, two major land use issues can be derived from this discussion of the Surface Mining Control and Reclamation Act and subsequent regulations. The first is the degree to which the requirements of the Act and regulations apply to FGC waste disposal at a mining site. As that issue has not yet been resolved by the Office of Surface Mining, the second issue is the degree to which disposal of sludges in mined areas would prevent compliance with the existing performance standards for reclamation.

3.7.3.2 Permanent Regulatory Program

The interim regulations that are presently in effect can be administered by states under their existing permit programs. Once the full regulatory program is in effect, however, states will have to, in many cases, revise their surface mining rules and regulations to comply with the requirements of the complete federal regulatory program in order to be approved.

Additional land use related requirements that might affect disposal of FGC wastes are not specifically included (although there are additional air and water requirements that will be dealt with elsewhere). Certain requirements of the final regulatory program are worth noting, however, mostly because they do pertain to either special regulations for certain mining sites or indirectly to economic requirements of mining operators.

Extensive requirements will exist for operators before a permit will be granted. The most pertinent ones surround the requirement for a reclamation plan. Such requirements include the plan for controlling the surface and groundwater drainage, plan for treatment where it is required, a plan for restoration of water recharge capacity where required, a plan for collection and reporting of ground and surface water quality and quantity data, a plan for a description of measures that will be taken to ensure that debris, acid-forming and toxic-forming materials will be disposed of in accordance with the Act, and finally, an estimate of the cost of reclamation. This latter requirement is important because a bond has to be posted to cover liability for the area of land affected by surface coal mining and reclamation operations under the permit (bonds are posted in one-year increments). These requirements would appear to make it essential to understand the implications of waste disposal in terms of operator liability.

In the section, "Disposal of Non-Coal Wastes", of the discussion report of the proposed permanent rules (43FR41767), the following quotation is relevant:

> "Another alternative which was reviewed concerned the utilization of surface mines for approved, centrally located sites for disposal of non-coal wastes by other mines, other industries, and even municipalities, in areas where suitable, physiographic and hydrologic conditions did not provide sufficient alternative disposal sites. The proposed regulations do not specifically address this issue, and public comment is solicited on the appropriateness of opening mine sites to outsiders for dumping."

A similar approach is suggested for the use of deep mines as disposal sites with the comment added that OSM is soliciting suggestions on the appropriateness of underground mines for disposal, as well as any differences which should be considered between underground and surface mine workings.

3.7.4 Land Use Considerations under State Solid Waste Management Regulations

A telephone survey of the ten EPA regions resulted in the selection of eight state solid waste regulations for review. As surface water, groundwater and stability considerations have been dealt with in Sections 3.2, 3.3 and 3.4, this review will focus only on land use considerations.

The following review focuses on three types of land use considerations:

- The types of regulatory control,
- The disposal site location requirements, and
- Closure and post-closure requirements.

While specific examples of types of regulation from specific states are cited, they are intended to be exemplary only. In other words, such examples are not intended to represent the best approaches, or the only approaches to these various land use-related considerations. However, on the whole, examples were chosen to illustrate the more restrictive requirements.

1. Types of Regulatory Control. Review of selected state solid waste management legislation indicates that for non-hazardous waste material criteria or standards for the handling, disposal, etc., are established at the state level. However, solid waste management plans are typically developed at a more local level (regional, county, etc.) with variable state involvement. Several approaches are illustrative.

- Under the Texas Solid Waste Disposal Act (Ch. 405, Art 4477-7, 1969 as amended) every county in the state has solid waste management powers and may develop county solid waste plans. Under the

Texas Municipal Solid Waste Management Regulations (1975, amended 1977), the Department of Health Resources policy on land use is given. "...regulations shall be prepared incorporating statements which will guide applicants for solid waste permits toward the selection of sites remote from public concern and encourage innovative management procedures such as recycling, land improvement, and the generation of energy. Further, the intention of the applicant shall be directed to the absolute necessity for land use compatibility of solid waste facilities with other land uses within the impact area of the proposed site." (Section A-5.) There is a note that the Department supports the decision that land use matters be managed by local government.

- Under Chapter 75 of the Solid Waste Management Rules and Regulations (Title 2 , Ch. 75, 1977), of the State of Pennsylvania, municipalities are to submit plans to the Department of Environmental Resources, including (a) resolution drafts and drafts of ordinances, contracts, and agreements that indicate the plan can be implemented, and (b) a summary of solid waste problems including future constraints expected to influence either solid waste systems such as available land, physical limitations, transport facilities, pollution regulations, or land use regulations, etc.

- The New Jersey Solid Waste Laws (Ch. 39, 1970 as amended), establish within the State Department of Environmental Protection, the authority to formulate and promulgate rules and regulations concerning solid waste collection and disposal. All the counties and the 14 community Hackensack Meadowlands District in New Jersey are designated solid waste management districts and develop their own waste management plans. Significantly, in cases where a district has established that there are insufficient existing or available sites for solid waste facilities and that there are difficulties in finding available space, state level authority for intervention in disposal site location is authorized by this act.

As with federal regulations, state level control over hazardous waste disposal is far more stringent than for non-hazardous waste. The degree of state level control varied among the state regulations reviewed, as illustrated in the two examples below. The second example appears to be a far more typical approach.

- In the State of Oregon, environmentally hazardous waste cannot be disposed of on any land other than real property owned by the State of Oregon, and designated as a disposal site. Under the Oregon Solid Waste Control Law (Ch. 409, 1969, as amended, Section 459.580) the licensee of a hazardous waste disposal site must deed to the state (for reimbursement) the portion of the site in or upon which hazardous wastes have been disposed of as a condition of the issuance of a license.
- Under Texas Solid Waste Disposal Act (op cit), The State Solid Waste Agency has the responsibility to control all aspects of industrial solid waste collection, handling, storage, and disposal. Where both municipal and industrial solid wastes are involved, then the agency has jurisdiction over the activity.

2. Disposal Location Requirements. Review of selected state solid waste management legislation and regulations indicates that criteria and/or standards (especially for hazardous material) are established at state level, but approaches vary. Two approaches are illustrated below:

- The State of California has published a manual for disposal site design.* Essentially, this manual establishes classifications of wastes by impact potential and classification of disposal sites by their ability to attenuate such impacts. If FGC wastes were classified as "Group I" wastes, their disposal would have to be at "Class I" sites: those that provide maximum protection from leaching and certain forms of runoff problems through occurring geological conditions.

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*Waste Discharge Requirements for Non-sewerable Waste Disposal to Land, California State Water Resources Control Board, January 1978.

- In a draft of Tennessee's Hazardous Waste Management Regulations (August, 1978), site permit applications are very specific. Such requirements include contour maps that show land use patterns and zoning within 2,000 feet of the facility, a preliminary geologic and hydrologic review of the area within 5,000 feet of the site, the life of the facility, the chemical and physical characteristics of the waste to be disposed of as well as transformations and/or residuals, and an outline indicating the plan of construction sequence for the proposed site, and closure plan.

The "hazardous" site requirements or permit requirements are used as examples as they are, in general, far more specific than those for non-hazardous waste disposal facilities. The latter, would typically be regulated by local codes, which generally contain "nuisance regulations," but in some cases include environmental performance criteria borrowed from state guidelines.

3. Closure/Post-Closure Requirements. Minimum standards for site closure are typically included in the selected regulations reviewed. These include final slope or stabilization requirements, cover and revegetation requirements for all types of sites. Monitoring, treatment of runoff or its accommodation by surface drainage, maintenance of liners, and requirements for underground drainage, exemplify requirements for hazardous waste disposal sites found in a number of state regulatory programs. A number of states have also established bond requirements as insurance that closure requirements are met and long-term maintenance can be required in some states for certain types of disposal situations.

Of the regulations reviewed, only one state, Kansas, established post-closure requirements for site land use planning, and even here this was for non-hazardous solid waste disposal sites only. The Kansas regulatory program (Article 29) establishes requirements whereby restrictive convenants may be made of the facility after closure, specify the period for which restrictive covenants apply, or describe modifications that could be initiated by property owners so that other land uses could be established. It is possible that understanding of the characteristics (i.e., risk-potential) of re-use of hazardous waste disposal sites would make such requirements infeasible for hazardous waste facilities. In fact, similar language is not used in the hazardous waste regulations for Kansas.

3.8 Air Related

Activities associated with the handling and transport of FGC wastes accelerate drying (solids content ranges from less than 10% to 60%) and increase the probability for the creation of fugitive air emissions, i.e. suspended particulates which are not emitted through a stack. It is these emissions which have become a concern of regulatory agencies.

As discussed throughout this section under RCRA, FGC wastes are provsionally considered "special wastes". However, it appears likely that they will not all be subject to the full set of hazardous waste regulations, particularly the design standards of Section 3004.

Section 1006 of RCRA directs EPA to integrate to the maximum extent practicable all provisions of RCRA with appropriate provisions of the other Acts of Congress which give EPA regulatory authority. One of the ways EPA has chosen to integrate RCRA with the Safe Drinking Water Act (SDWA), the Clean Air Act (CAA), and the Clean Water Act (CWA) is through the use of Human Health and Environmental Standards. Each of them - the groundwater, surface water, and air standard - establishes an overriding standard for treatment, storage, and disposal facilities by incorporating relevant limitations established under those acts. Since the primary pollutant generated by FGC wastes is suspended particulates, the Clean Air Act as amended (CAA) would apply.

Prior to 1978, all dust generated in earth-moving and materials handling during FGC waste disposal would have been considered fugitive dust emissions. However, the prevention of significant deterioration (PSD) regulations established in 1978 by EPA under the Clean Air Act of 1977 clearly defines fugitive dust as consisting of "particles of native soil which is uncontaminated by pollutants resulting from industrial activity." Particles so defined are not subject to PSD regulations in FGC disposal activity. This implies that only the fugitive emissions of FGC wastes, per se, and any dust generated in the handling of aggregates used in FGC waste treatment,will be considered in PSD increment determination for new waste handling, treatment, and disposal facilities.

However, if these activities occur on the utility site, they may be reviewed in the larger context inclusive of stack emission from the plant itself. The (PSD) regulation applies only to particulate and sulfur dioxide pollutants at this time and establishes the area classifications and limits for increases (increments) in concentrations of these pollutants above existing levels as shown in Table 3.6.

Class II PSD provisions of the Clean Air Act Amendments apply to most areas of the country designated by states as being in attainment of National Ambient Air Quality Standards, except for areas initially designated Class I. Numerous permit requirements are now mandated by law for certain modified stationary sources (greater than 100 tons per year (tpy) potential uncontrolled emission rate).

Permit review needs are considered according to the level of technical review needed; PSD regulations allow for three levels of permit evaluation. Level I permit applications are sources which are not subject to non-attainment or PSD review because the emission rate is below the statutory cutoffs or reductions in emissions are expected. Applicants are subject to State Implementation Plan (SIP) and/or New Source Performance Standards (NSPS) review. New source applicants deemed subject to non-attainment or PSD review are made aware of measures that would eliminate non-attainment or PSD review. Such measures could include site relocation, sulfur restrictions in fuel, emission standards tighter than the SIP or NSPS and process equipment changes that are less polluting, among others.

Finally, Level III permit applications, where predicted ambient air concentrations are significant after Level II screening, are referred for review by dispersion modeling. If the modeling indicates that particulate emissions, for example, will cause or contribute to ambient air concentrations which exceed the maximum allowable increases for Class I areas, the state may still issue a permit. however, the emitting facility must give assurances that its emissions together with all other sources will not exceed the maximum allowable increases over baseline concentrations stipulated for Class II areas for particulates.

Table 3.6

PSD Limits on Increases in Pollutant Levels
($\mu g/m^3$)

Basis: All numbers in microgram per cubic meters

	Permitted Increments			NAAQS
	Class I	Class II	Class III	NAAQS
SO_2				
Annual	2	20	40	80
24-Hour	5	91	182	365
3-Hour	25	512	700	1300(s)
TSP				
Annual	5	19	37	75 60(s)
24-Hour	10	37	75	260 150(s)

Note: All 24- and 3-hour values may be exceeded once per year.

NAAQS: National Ambient Air Quality Standard (Primary)

Source: [53]

In absence of a definitive precedent, it is difficult to assess the specific regulations applicable to FGC disposal facilities. For example, if the disposal site and operations are considered part of a fossil-fuel fired steam electric plant, the emission cutoff rate for PSD review is 100 tpy, otherwise it is 250 tpy. Further, if the disposal facility is considered part of the fossil-fuel fired utility, and the utility has "converted (to coal) from the use of petroleum products, or natural gas, or both," then "for purposes of determining compliance with the maximum allowable increases in ambient concentrations" of particulates, the particulate emissions are not taken into account.

The question as to whether or not the FGC disposal facility and activities are to be considered one of the 28 major emitting facilities is critical to an understanding of which federal and/or state SIP regulations are applicable.

In "non-attainment" areas, i.e., those areas where Federal Ambient Air Quality Standards have not been attained, new FGC waste disposal activities could be subject to a review procedure including "emissions offset" considerations. These considerations, if applied by the responsible permitting agency, would involve the implementation of equal or greater reductions of existing emissions of the pollutant of concern as a tradeoff to allow the emissions increment associated with the proposed disposal activity.

3.9 National Energy Act of 1978

In 1978 the National Energy Act (NEA) was passed by Congress and encompassed five separate bills:

- National Energy Conservation Policy Act of 1978
- Powerplant & Industrial Free Use Act of 1978
- Public Utilities Regulatory Policy Act
- National Gas Policy Act of 1978
- Energy Tax Act of 1978

At present, detailed regulations to implement the overall framework of NEA are being worked out by the Department of Energy (DOE). The regulations would promote the use of coal, renewable energy sources, and other alternative fules over oil and natural gas wherever possible. While the full impact of NEA on utility and industrial power plants needs further definition, the following appear to be indicated:

a. All new boilers, gas turbine and combined cycle units with a capacity larger than 10 MW will be prohibited from using oil or natural gas unless specifically exempted by DOE.

b. Existing facilities that are coal capable but not using coal now may be required to switch to coal or an alternative fuel. Financial capability to use coal or alternate fuels will be considered by DOE. DOE will consider exempting an existing boiler without the furnace configuration and tube spacing to burn coal. However, addition of particulate and FGD systems may not be considered substantial modification preventing a switch to coal. Furthermore, derating of less than 25% by switching to coal will not be considered substantial. These regulations will apply to single units of 100 MMBtu/hr or more or multiple units in one site which is aggregated by design capable of a fuel input rate of 250 MMBtu/hr or more.

It is anticipated that NEA will encourage use of coal over the next twenty years. Additional solid wastes and wastewater will be generated by a switch to coal. Focus on these incremental problems is under RCRA. As regulations under NEA and RCRA develop further, proper meshing of these to meet the overall objectives of a national switch to coal and environmentally sound disposal of coal-related wastes is essential.

4.0 ENVIRONMENTAL IMPACT CONSIDERATIONS

4.1 Introduction

This section consists of an evaluation of the results of previous and ongoing assessments of the environmental impacts of FGC waste disposal. As summarized in Table 2.5, there are some ongoing field-scale environmental studies of FGC waste disposal. As may have been seen throughout the text below, there are very few published results of completed field-scale studies of this subject. Thus, much of what appears in this report is evaluation arrived at by combining the knowledge gained from FGC waste characterization studies (Volume 3) with the emerging results of ongoing field-scale studies.

The focus of this evaluation is the set of potential impact issues identified in Section 2.4 above. In addition to attempting to prioritize this evaluation for each disposal option as described in 2.4 attempts have been made to point out, wherever possible, the degree to which the potential importance of various issues remains unresolved in light of the assessments to date. Further, attempts are made to characterize the degree to which planned research may be expected to resolve these issues. Finally, remaining unresolved issues are linked to future research needs on the basis of the apparent magnitude and uncertainty of their impact potential.

As an overview of all the text that follows, it is most important to remember that there are no universally significant environmental issues for all FGC waste disposal options at all disposal sites. The significance of each issue for any given disposal operation tends to be a site-specific function of three variables:

- Waste characteristics,
- Disposal practice, and
- Nature of the receiving environment.

Thus, impacts are site-specific and cannot be easily generalized over a region. Furthermore, the existing regulatory framework, if successfully implemented, could prevent or minimize significant adverse impacts. Against this background, some broad generalizations on the potential environmental issues can be made on a regional or national basis. Potential impacts are assessed on the disposal by the major potential disposal option of ash and FGD waste.

4.2 Land Disposal

4.2.1 Physical Stability Overview

Stability of a given disposal option can be viewed from the perspective of normal versus abnormal impacts. Normal impacts are deterministic, that is, they can be expected to occur under usual conditions. Abnormal events, however, are probabilistic. Such events are defined as those which are not part of planned occurrences associated with the operation or post-closure activities at the disposal site.

In the present case, abnormal events which may affect site/sludge stability involve vibration, liquefaction and inundation of the site. These events include earthquakes, presence of heavy machinery, high local traffic volumes, flooding, and altered runoff or groundwater flow patterns. Good design and proper operation practices can reduce the probability of these events occurring and while it is impossible to reduce it to practically zero, it must be emphasized that with good engineering practices, the state of the art is such that the impacts which will occur under normal circumstances are minimal. Good engineering and operations will be considered separately for each of the three land disposal options.

Wet Ponding

In the normal course of events, FGC wastes disposed of by ponding will be exposed to the effects of weather: freezing, thawing, evaporation, precipitation and runoff. The resulting impacts upon stability of the waste are also determined by operational procedures in effect at the particular site. Thus, the soundness of engineering decisions on site operations determine the extent of impacts. The question of post-closure use of the site will weigh heavily in engineering decisions, along with economic considerations (which are dealt with in Section 6). This issue becomes in reality, a public policy issue, considered under "land use" in this section.

Good engineering begins with an understanding of the processes working in and upon the medium at hand and then in taking advantage of them to obtain the desired results. The ponding disposal option involves two sets of processes--bulk physical properties of FGC sludges and grain properties, both physical and chemical. The potential physical impact issues for FGC wastes are settling, liquefaction and dewatering. The grain properties of interest are bonding of the weaker and the pozzolanic types and those resulting from grain morphology (size and shape).

While it is broadly true that crystal morphology and the sulfate/sulfite ratio in FGC wastes do impact on physical properties, no direct relationship has been demonstrated. In the wastes tested and reported in the literature, sulfite wastes have tended to consist of platy particles of smaller size than rounder sulfate particles. Because of these differences in particle size and morphology, sulfite wastes have tended to be more compressible, weaker, harder to dewater but less susceptible to liquefaction failures than sulfate wastes. If sulfite particle size and shape were altered to resemble sulfate particles, less differences in behavior may be observed. In the field, with possible interactions and alterations in both sulfite and sulfate particles, the situation would be much more complex. At present, only indirect indications of behavior as a function of sulfite/sulfate ratio have been developed.

Consideration of the abnormal event leads to cost/benefit considerations. While it may be less expensive to merely build a retaining wall to contain raw, undrained sludge, than to obtain maximum strength and stability by dewatering (which also involves wall construction), the latter poses much less threat to life and property if the wall fails. In the former case, a wall failure due to earthquakes would most likely cause an immediate liquefaction of the sludge and a flow of such velocities that would be expected to endanger life and property if they were in the flow path. Liquefied sludges may flow as fast as water and have a larger momentum. They are potentially as dangerous as mud flows which have caused significant damage in the Pacific Northwest and elsewhere.

It should be stressed that with good engineering, abnormal events will have a minimal or reduced impact, while in the absence of proper planning and data, the impacts could be severe. However, it may be noted that while structural engineers can devise a safe foundation for just about any site, the costs would probably outstrip the potential benefits of such structures on the project involved.

In a study of six sludges including lime, dual alkali and dilute acid wet scrubbing processes at the University of Louisville [22] , it was found that the silt-sized particles of sulfite sludges will settle to 30-35% solids while the sand-sized sulfate sludge particles will attain 60-65% solid content. When dewatered, these sludges can be reduced to 50 and 80-85% solids content, respectively. Researchers at Ontario Hydro noted that studies by others obtained a maximum of 50% solids following clarification of sludge in a lagoon [44] .

Research at the University of Louisville [54] has verified that both sulfite and sulfate sludges lose strength when agitated. Sulfite sludges will build up strength over time, but this strength will disappear upon vibration. Sulfate sludge is nonplastic and although it is more sensitive to changes in moisture content, it will also lose strength when agitated due to liquefaction. Because liquefaction has the effect of removing interstitial waters by packing the grains closer together, it is a process which may be employed to increase the strength of a settling or settled sludge. Induction of liquefaction in the sludge by applied vibrations followed by pumping or draining the expelled water leaves a denser, drier sludge mass. Until a sludge has undergone liquefaction, it can be classified as potentially unstable, therefore, liquefaction has always been regarded as a process to be feared. Controlled liquefaction can be a definite advantage.

Because it is known that at an optimum moisture content compacted soils exhibit a maximum strength, dewatering to reach that moisture content is a useful engineering technique. Water content can be reduced by centrifuging, vacuum filtration and solids (normally fly ash but sometimes local soils) addition. The material may then be trucked or pumped to the disposal site. Physical stability of the waste may be of great importance to the possibility of reclaiming these sites. The fact that dewatering of sulfite sludges is slow while that of sulfate sludges is more rapid has been clarified by ongoing research at the TVA's Shawnee Test Facility [55] Current efforts at Shawnee have focused on the morphology of sludge particles as affected by the type of absorbent used in the scrubber. They verified the difficulty in dewatering sulfite sludges but specified that lime sulfite sludge because it entraps water between its aggregate crystals is more difficult to dewater than limestone sludges. The results of dewatering as noted by Hagerty et al [54] are a decrease in compressibility and an increase in structural strength of the material. The addition of sand has been observed to achieve these properties.

The grain properties of FGD sludges vary with their chemistry. Sludges have been characterized (see Volume 3) as sulfite-rich, sulfate-rich, or mixed, the latter containing significant fractions of sulfite and sulfate. The characterization of sludges performed at the University of Louisville has concluded that sulfite sludges are highly compressible, even after compaction, have low strength and are impervious to semi-impervious. Sulfate sludges are of low-to-medium compressibility, and have similar permeability characteristics when compacted. Sulfate sludges may collapse unpredictably due to liquefaction when saturated. In analyzing research and studies performed by others, SCS Engineers [28] have reported that light compaction of dewatered sludge will result only in a small improvement of structural strength. Another researcher [56] has found, however, that the dewatering and compaction, especially of sulfite sludges has reduced the compressibility significantly. A mixed sulfite/sulfate/sludge with 35% water content was subject to liquefaction after 30 days in a 30-cm layer [22]. Studies of dewatered sludge behavior under loading have produced varying results. SCS Engineers [28] have reported that other researchers have found that settlement is unavoidable even after heavy compaction, although it may be less than the settlement of most common soils under the same circumstances. Deposits of unstabilized sulfite sludge filter cake might be highly compressible, even for light structures [22]. The same authors have reported that the compressibility of sulfite sludge is within acceptable engineering limits for light to medium weight structures. Investigations of uncompacted sludge have determined that under low confining pressures, sludges may lose their shear strength under dynamic loading. Sulfate sludges not only consolidate less but undergo consolidation much quicker than sulfite sludges. For example, an uncompacted sulfite sludge has been observed to consolidate by 10% of its original height of 20 feet in two months, while an identical sulfate sludge layer completed its lesser consolidation in two weeks.

Physical blinding has been observed between FGC sludge and soil layers in contact which has implications for leaching at some disposal sites. These sludges have insignificant effective cohesion, however, which places an upper bound on the load they can withstand. Field values have been observed to be lower for all physical characteristics including permeability, maximum dry density and compressive strength. Pozzolanic activity may produce a partly cemented material which is brittle and friable, rather than cohesive [57]. In an ongoing study of waste products from certain western coals (lignite) the fly ash was found to be highly alkaline and has been successfully substituted for lime/limestone in scrubber systems. This system (used at Milton Young Station in North Dakota) produces an alkaline gypsum sludge in which pozzolanic activity has been observed. The physical properties of this sludge are within the ranges for most lime/limestone sludges [58]. The moisture content of this sludge, which is approximately 30%, makes it a good candidate for ponding.

Field behavior of dewatered sludges has been studied by three research groups: University of Louisville [22,56], Sikes and Kolbeck [57], and Aerospace, Inc. [37]. The former have observed that freezing of sludges may cause dewatering or layering. The Aerospace study [37] reported that dumped piles of partially saturated gypsum sludge slumped when wetted by rainfall. In all likelihood, this precipitation destroyed capillary suction. Properly compacted gypsum wastes would not be subject to loss of stability upon saturation. Such deposits will form an impervious surface layer (due to pozzolanic action) which has been observed to crack during freeze/thaw conditions. This presents the possibility of new opportunities for leachate formation and may imply that gypsum sludge disposal sites be maintained regularly as a function of weather conditions. The latter group performed a study comparing field and lab tests of two types of fly-ash sludge deposits. The inplace dry density of the two sludges were 85% and 99% of the laboratory value; inplace moisture contents were 69% and 58% of lab optima. The field compactions achieved were 85% and 99% of the theoretical optima. The waste which performed best in the field had a finer range of grain sizes, a lower optimum moisture content and higher wet and dry densities and was chemically less complex.

Many of the major physical properties of FGC wastes have been investigated to some degree. A particular lack of information exists for the compressibility of dewatered fly ash wastes. Further research is needed in correlation of field performance with laboratory tests. The conditions which will induce liquefaction require greater definition.

4.2.2 Public Policy and Land Use

The focus of this review centers around three aspects of FGC waste disposal by impoundment:

- Site location,
- Post-closure land use, and
- Impact potential of disposal on adjacent lands.

It should be noted that for public policy considerations, in particular, issues identification is somewhat speculative based on existing (but changing) regulatory framework and projected incremental land requirements due to projected increases in the use of flue gas cleaning systems well in the future.

Site Location

The site location issue may be viewed from two perspectives: (1) space requirements for disposal of the cumulative, increasing generation of FGC wastes and (2) the location of a specific FGC disposal site.

A typical 1000-MW plant will require 160 to 280 hectares (400 to 700 acres) for disposal of ash and FGD sludges over a lifetime of 30 years depending upon the type of coal to be used and the region in which it is located. The 160 to 280 hectares (400 to 700 acres) include only the excavated area (dry disposal or ponding); the actual disposal area required may be much larger since land would be required for access roads, truck parking and unloading areas, and buffer zones to screen off the disposal area. It is anticipated that in the future public pressures will result in greater attention to buffer zones in populated or recreational areas to minimize the adverse aesthetic impacts of disposal areas.

The area of land required for disposal of FGC wastes from a typical 100-MW industrial boiler may be more than 10% of that required for a 1000-MW utility boiler discussed above if the FGD systems are identical nonrecovery units. The height of a managed fill for an industrial boiler is likely to be less and, hence, proportionately more area would be required (although the volume of wastes for a 100-MW boiler will be 10% of that for a 1000-MW boiler. Cumulative wastes generated by an industrial boiler during its lifetime will require from 16 to 26 hectares (40 to 65 acres) for the disposal area along with perhaps an additional 20 hectares (50 acres) required for unloading areas, vehicular movement and buffer zones. It should be emphasized that many industrial units may employ sodium based FGD processes and produce liquid wastes. In many cases, the latter may be integrated into the water and waste management plans of the whole industrial plant (rather than treated or disposed of as FGC wastes.

Based on the data concerning the cumulative generation of coal ash and FGD wastes presented in Section 2, the same order of magnitude estimates on land requirements for disposal are summarized in Table 4.1. These are for illustrative purposes only and not intended as estimates on land use.

It appears that the following conclusions on land use are valid:

Table 4.1

Cumulative Land Requirements for Disposal of FGC Wastes

Basis:

1. Pre National Energy Act of 1978 estimates on coal utilization.
2. All FGC wastes disposed on land as moist material in lifts of 10 meters (32.8 feet).
3. Only excavated disposal area mentioned. Actual land required including buffer zones and access roads may be 2 to 3 times the listed amount.

		By 1985		By 2000	
No.		Sq km	(Acres)	Sq km	(Acres)
1.	Coal Ash Alone	39.6	(9750)	130	(32,100)
2.	FGD Waste Alone	16.2	(4000)	65	(16,050)
3.	Total FGC Wastes	55.8	(13,750)	195	(48,150)

Source: Arthur D. Little, Inc.

- From a regional or state land use perspective, these land requirements are not large.
- Federal Regions 5, 4, 6, and 3 (in that order) are projected to require maximum total land and maximum incremental land. While individual disposals would result in a loss of land for other purposes, the impact when considered on a regional or national scale is not very large.
- Much of the land area required for disposal between 1985 and 2000 would result from the establishment of new utility plants and industrial boilers. It is anticipated that these "energy centers" will require a larger land area than previous facilities and hence be sited in relatively rural areas. Political and economic factors are expected to increase land use planning for such uses and place additional regulatory constraints on utilities and industry. Potentially, demand could arise to combine utility plant and disposal area into one site, reducing requirements for off-site disposal.

While land requirements for FGC waste disposal are not large on the national or regional scale, at the local level land use could become an issue on a site-specific basis. FGC waste disposal areas are usually zoned for industrial use. This land use may not be compatible with other uses such as residential, commercial, and recreational.

One of the largest operating FGC waste systems utilizes a 560-hectare (1400-acre) impoundment for the disposal of treated sludges from a two unit 1650-MW power plant. While a third unit is under construction, the impoundment was designed for 30-year use, assuming a filled depth of 400 feet of waste [59]. This example may be exceptional because of the large operation size combined with impoundment disposal planned for one site. Future location problems for such large impoundments could exist, although they are expected to be location specific. A "hazardous" or "non-hazardous" designation for FGC wastes would not alter land requirements for disposal but could potentially increase location-specific problems with siting.

The aesthetics of a disposal operation can have an effect on site location due to local public reaction. Such problems, where they occur, are not expected to be significantly different from location problems for other types of waste disposal areas. If anything, they may be less because of the uniform appearance and relative absence of odor with FGC wastes.

Post-Closure Land Use of Impoundments

Considering the amounts of land area that could be required for FGC waste disposal on a site-specific basis, the issue of post-closure land use is an important one. Constraints on post-closure land use are related to the site, type of waste, method of disposal and climate. Many of the specific issues in question concern waste characterization and its relationship to long-term disposal physical stability and chemical stability. Research in these areas is discussed in greater detail under each of those headings, with the issues addressed here only as they relate to disposal site post-closure land uses.

For wet impoundments that are drained following disposal operations, the major issues are those discussed below for dry impoundments. Where water cover is intended to be left over the disposal impoundment, several additional issues exist:

- The water quality of the supernatant water,
- The impact potential of the supernatant water on terrestrial and aquatic species, and
- The impact potential of released water on downstream users.

4.2.3 Wet Ponding

Some of the generic environmental issues pertaining to any method of FGC waste disposal on land were discussed above. In this subsection, the focus will be on wet ponding.

Physical Stability Issues

The issues concern liquefaction and other abnormal events. There are several aspects to this issue:

- Development of appropriate engineering basis for the particular waste involved,
- Design safety factors to be adequate for the specific site taking into account the potential impact of abnormal events, and
- Adequate monitoring of the site including embankments, dikes or dams.

Physical stability impact issues can in principle be minimized with proper engineering design and operation.

Water Quality Considerations

Many, if not all, FGC waste disposal water-related impacts arise from the migration of leachate and/or runoff. Consequently, laboratory tests of leaching characteristics of FGC wastes are of general relevance to all land-based disposal options. Impoundment of FGC wastes with water cover can present a significant potential for related impacts because the head of water promotes percolation of water through the wastes and would (theoretically) eventually cause the water table to rise to pond level, maintaining an intimate contact between waste and groundwater. This process can be avoided by:

- Wet stabilization process, wherein the settled wastes undergo pozzolanic reaction to produce a layer of very low permeability. The Dravo wet process is an example.
- The use of an impermeable liner under the pond to contain the leachate. Liners are not fully proven at present; research efforts now underway should produce useful data on their applicability in the immediate future. For practical purposes, containment may be considered effective if the leakage is adequately delayed and/or maintained at a low rate. Thus, the effectiveness of liners and their rates of deterioration in contact with FGC wastes in various environmental settings is an important consideration in assessment of environmental impact of FGC waste disposal in impoundments with a maintained water cover.

Of primary importance to water impacts is the rate of pollutant mass release (mass/time) to the surrounding ambient water via leachate. This quantity may be estimated by the product of leachate quality (mass/pore water volume) and waste permeability/length/time by disposal area. The actual pollutant release rate cannot exceed this amount, although in dry seasons the actual rate of leachate generation may be far less than indicated by the product of permeability and area. Setting aside the very important site-specific considerations such as leaching solution characteristics (water quantity, quality, and flow pattern), surrounding soil permeability, and disposal site area, an intrinsic waste property of particular significance to water contamination is pollutant flux (mass/

area/time) which is the product of each pollutant's equilibrium leachate concentration and the permeability of the waste. This waste property could be established by standardized leaching and permeability tests. At this time, the development of standard leaching tests continues. No procedure has been generally recognized, nor have general interpretive rules been established to relate these intrinsic leaching properties of wastes to field environments. Nonetheless, comparisons of intrinsic pollutant flux for various FGC wastes have been reported indicating that the intrinsic flux from chemically stabilized FGC wastes would be one or two orders of magnitude less than from unstabilized FGC wastes. However, precise estimates on the total impact of chemical stabilization should include:

- Impact of surface runoff, and
- Impact of permeation on a site-specific basis.

A number of R&D programs on leachates have produced data on leaching behavior as described in detail in Volume 3.

Once a waste is placed in any type of land disposal site, its initial contact with water would tend to flush out interstitial waste liquors: initial leachate quality could be similar to that of the occluded liquor. The initial volume of water within the waste is equal to the pore volume (porosity times the total volume of waste). After several pore volumes of water have passed through the waste deposit (PVD = pore volume displacements), most of the occluded water will have been flushed and the leachate concentration of major ions is expected to approach steady state corresponding to the solubility of the major constituents in the solid phases of the waste. These solubilities are often pH and temperature dependent, and thus the long term leachate quality will also depend on pH and temperature. In theory, trace metals also approach an equilibrium value. However, Rossoff, et al.[37] investigated nine trace metals and could find no evidence that solubilities of metallic compounds (oxides, hydroxides) controlled the equilibrium concentration.

Leo and Rossoff [60] have investigated the first flush effect for five specific disposal scenarios and find that the first flush of occluded waste liquors may affect leachate quality for as little as ten years (for ponding) or as long as 1300 years for a managed landfill of stabilized sludge. Water quality impacts of ponding are consequently likely to be controlled by the long term equilibrium mass release rate of pollutants and the nature of receiving waters on a site-specific basis. The long term mass release rate of pollutants is controlled by equilibrium leachate quality and the rate of leachate and runoff generation. The rates of leachate and runoff generation are affected by many variables including meteorology, hydrology, site management, and waste permeability.

Laboratory Tests of FGC Waste Leachates

Laboratory tests of leachate quality are indicative of relative differences between wastes but are less than fully relevant to assessment of disposal impacts because certain environmental conditions cannot be reproduced in the lab. Further discussion of FGC waste leachate quality may be found in Volume 3.

It was reported [37,60] that equilibrium (40-50 PVD's) leachate concentrations were not significantly dependent on pH. TDS and sulfate levels tended to similar values of approximately 2000 ppm and 1200 ppm, respectively, regardless of waste type. It was indicated that these concentrations are probably controlled by the solubility of the $CaSO_4$ component of the sludge. The only exception was a sulfite-rich sludge whose equilibrium TDS and $SO_4^=$ concentrations were much lower than the others, indicating that $CaSO_4$ solubility was not dominant for this sludge. These leaching tests were conducted under aerobic conditions, while field conditions for leaching of sulfite-rich sludge are more likely to be anaerobic (although oxidation of the sulfite also probably occurs in the field). Thus, it is reasonable to expect that under field conditions, sulfite-rich FGC wastes, even those containing greater than 5% $CaSO_4$, will yield leachate whose equilibrium TDS and SO_4 concentrations will be significantly less than indicated by $CaSO_4$ solubility. However, the leachate concentrations of major species in mixed and sulfate-rich sludges are expected to be controlled by $CaSO_4$ solubility.

Sulfite-rich sludges in anaerobic conditions are expected to generate leachate having a high chemical oxygen demand (COD) present as total oxidizable sulfur (TOS). Without relevant field testing and experience, it is difficult to assess the importance of this TOS content to water quality. Groundwater in the saturated (water table) zone is deoxygenated by microbial activity. When drawn to the surface in wells, it is well aerated during the pumping or sampling process. Only where surface water bodies receive leachate or runoff-related flows is the oxygen demand expected to pose any potential environmental problem, and the extent of this problem would be extremely site-specific.

The results of leaching tests conducted to date tend to indicate that the degree of oxidation of the waste can lead to significant differences in leachate quality, with sulfite-rich sludges expected to yield leachate with lower TDS and SO_4 concentrations, but with a greater COD (Lunt, et al.).

As reported in Volume 3, there is some evidence to suggest that sludges containing fly ash yield leachate containing significantly higher levels of some trace metals (e.g., arsenic) than ash-free sludge (Radian, Rossoff,et al., Final Report 63-02-1010). However, Leo and Rossoff [61] conclude that the differences in leachate quality are not dramatic and that flyash removal upstream of the scrubber will not significantly improve the trace element leachate quality in relation to the pollutant hazard. Unfortunately, so few tests have been conducted with ash-free FGC wastes that this question is not clearly resolved.

Equilibrium leachate concentrations of major constituents show no dependence on scrubber absorbent (lime, limestone, double alkali) but trace element leachate quality is observed to depend on absorbent and type of coal [62].

The quality of leachate depends not only on the type of waste, but also on the nature of the leaching solution. Leaching may occur in several ways, including surface leaching of impermeable materials, with subsequent runoff which may eventually enter surface or groundwater; by rainwater percolating downward through permeable wastes; or by groundwater flowing horizontally through the waste mass. Rainwater, the leaching solution in the first case, will be well aerated, and of variable pH (4-7) in the U.S. (more acidic in the NE, more basic in the west and south). Percolating rainwater and groundwater quality will change as it interacts with the waste, and is likely to be reduced in dissolved oxygen by mixed and sulfite-rich sludges. Most FGC wastes are neutral or alkaline and thus the leaching solution, even if initially acidic, will tend to become more basic.

Preliminary results from column leaching tests at WES [62] indicate no significant variations of leachate quality with pH of leaching solution. These results are corraborated by the study of Duvel, Rapp and Atwood [63] comparing leachate quality for two different leaching solutions: distilled water and a synthetic solution analogous to acid mine drainage. Certain trace metals were leached only slightly more effectively at low pH, but a precipitate of iron sulfide was formed. Leo and Rossoff [61] found that the trace metals Pb and Zn are leached more readily by acid leachate while only Pb, of the trace metals analyzed, showed a significant difference in aerobic/anaerobic comparisons (higher for anaerobic). Data on leaching from stabilized FGC wastes is not fully conclusive data although reduction in trace elements is reported [60].

Besides leachate quality, FGC waste permeability is an important disposal parameter amenable to laboratory testing. However, as discussed in Volume 3, laboratory tests of permeability may not be relevant to permeability in the field. Sample disturbance; passage of water around, rather than through, the sample; and stratification of field deposits are common causes of unrepresentative laboratory results, while weathering, particularly freeze/thaw cycles, are expected to change in situ permeabilities over time.

Unstabilized sludges consistently exhibit permeabilities of 10^{-5} to 10^{-4} cm/sec while stabilized sludges show permeabilities one to two orders of magnitude lower. Sulfite-rich FGC wastes are generally less permeable than sulfate-rich ones because of their "flat" crystalline morphology. Addition of fly ash, fly ash and lime, fly ash and cement, or the proprietary additive Calcilox® will reduce permeabilities by about an order of magnitude although the reported effectiveness of treatment in permeability reduction is quite variable [37,60,64].

To close this discussion of laboratory tests pertinent to wet impoundments and all other land-based disposal options, soil attenuation of leachate constituents must be considered. Because of the great variety of soils and wastes, this again will be a highly, site-specific consideration, but laboratory results should provide some guidance on the question of whether the soils surrounding a disposal site will be capable of retaining potentially problematic ions associated with leachate. Two studies that may offer guidance in this regard are:

- Radian study for EPRI [40]. This study entailed not only laboratory measurements of leachate/soil interactions, but also the development of an analytical model which permits scale-up of their laboratory results to facilitate field-scale estimates of soil retention. Anionic forms were not retained by the bulk of solids. Radian tests involved synthetic mixtures of soils (without organics) and field samples. Since trace element levels were low, Radian increased concentration to study effects.
- U.S. Army Materiel Command, Dugway Proving Ground is also performing soil attenuation studies, the results of which had not been published as of early 1979. However, preliminary results are broadly consistent with the Radian findings.

Field-Scale Research

Pilot scale tests of pond disposal of FGC wastes have been undertaken at TVA's Shawnee facility and by Louisville Gas & Electric Co. (Paddy's Run) while full scale pond disposal is being monitored for potential well contamination at the Bruce Mansfield disposal reservoir by Pennsylvania Power & Light. Preliminary results at Shawnee and Bruce Mansfield indicate no significant contamination of groundwater to date [60,65]. However, these results may not be significant because the disposal ponds have been in operation for less than five years and there is no reason to expect that pollutants would have migrated from the site via groundwater in such a short time. This points out a fundamental problem in groundwater protection: field verification and experience is gained very slowly. Laboratory analyses of supernatant, leachate, and permeability of samples from field disposal sites provide valuable information relevant to actual disposal conditions:

- It was reported that compaction at the bottom of these relatively shallow ponds can reduce the waste permeability by a factor of 2 to 5. Aerospace [61] concluded that compaction at the bottom of a 12 meter deep pile of FGC waste will decrease permeability by one order of magnitude.
- Aerospace studies [50,61] note that at Shawnee, after allowing for weather, leachate concentration of the major solubles dropped to one-half to one-third of input liquor.

Aerospace Corporation, at TVA's Shawnee facility, is investigating an underdrained pond system in which leachate is collected for treatment or reuse. One potential advantage of this system for water-related impacts is the reduction in head which accompanies drainage, thus reducing percolation into the region below the site. In areas with appreciable rainfall, underdraining requires [39] dividing the disposal area into several sections (over the life of the plant) using one section at a time from the surrounding water bodies. Reduction in the amount of leachate generated may be accomplished for ponding scenarios by diverting the entry of surface runoff from adjacent areas. The high water content and fluidity of impounded FGC wastes make site management to promote runoff and eliminate standing water difficult or impossible to achieve.

Waterways Experiment Station of the U.S. Army Corps of Engineers has been conducting field studies on the effects of FGC waste disposal on adjacent soils and grounwaters. While final results are likely in 1979, it is noted that earlier WES reports on three FGC waste disposal sites [66] have been reported. These sites had been utilized for FGC waste disposal for five to nine years. Well samples were analyzed for major soluble components of sludge and several trace metals. Soils were extracted and analyzed to determine if adsorption on soils was occurring that might attenuate leachate migration. Distinct leachate plumes were not resolved and migration patterns were reported to be complex. However, careful statistical tests reportedly revealed that groundwater at all three sites exhibited increased contaminant concentrations as a result of the disposal operation and that there was little or no evidence of attenuation of some pollutants by the soil [66].

Aerospace [61] has performed an analysis of the potential for groundwater pollution in terms of the flux of TDS to subsoil over a 150 year period. They considered five disposal scenarios including impoundment of stabilized and unstabilized FGC wastes, both with and without diversion of runoff, and managed landfill of stabilized waste. The analysis incorporates certain site-specific aspects by specifying that the natural groundwater recharge rate is 10 in/year and the depth of waste is 30 feet. Their analysis is not generally applicable to all disposal environments. According to that analysis, diversion of runoff from an impoundment such that it is not covered by water, is more effective than chemical stabilization in reducing the potential for prevention of groundwater contamination. A well managed landfill of stabilized sludge, including grading to promote runoff, presents the lowest potential for groundwater contamination according to their report. However, the promotion of runoff is not always consistent with the protection of surface water quality on a site-specific basis.

Site management over indefinite periods of time may thus be a major requirement for pond disposal due to the potential for impact without strict management. However, Aerospace [61] also concluded that the underdrain system with collection, and treatment or reuse of leachate would result in improved physical stability such that long term site management is a much less serious problem. Furthermore, liners would not be required to protect groundwater. The ideas expressed in that report [61] are being field tested at the pilot scale at TVA's Shawnee plant at this time.

Other Potential Impact Considerations

In addition to the land use and water quality issues discussed above for wet impoundments of FGC waste, two other types of potential impact issues were identified in Section 2. These are air quality related and biological issues. The former are considered of little or no environmental significance for FGC waste disposal in wet impoundments, and have not been the subject of empirical environmental assessment studies. Biological issues such as revegetation requirements, could be of significance, but also have not been studied empirically for wet FGC waste impoundments. This point is discussed in the summary of data gaps and research needs (Section 4).

4.2.4 Dry Disposal

Four types of FGC waste may be disposed of in dry form:

- First, bottom and fly ash which have been collected pneumatically; often these two material flows are combined for disposal but this is not always the case.
- The second group includes gypsum sludges from conventional FGD systems on low sulfur coal or forced oxidation FGD systems.
- The third group is the stabilized sludges. Both sulfite and sulfate sludges are stabilized by chemical treatment and although dewatering is often a preliminary step to stabilization, it is not a stabilization process by itself. Stabilized sludges are often placed in the disposal site while still containing as much as 30% moisture. This water is, however, chemically bound and plays an important role in the curing process which renders stabilized wastes into much harder aggregates.
- The last dry wastes are those generated by dry sorbent desulfurization techniques. These techniques are currently receiving a high level of attention and commercial systems should be operative in the early 1980's. Unfortunately there exists a large data gap about the materials produced by these processes and this is a very important area to be focused upon as a result.

Physical Stability Issues

The generalized discussion in Section 4.2 also applies here. In addition, because so many of the inherent problems of FGC waste have been ameliorated by stabilization or disposal without water, the physical stability impacts associated with this option are virtually negligible when good disposal design and practice are followed. Normal field conditions do have the potential to interfere with the proper resolution of stabilization processes and to inundate the dry wastes. Thus, the engineering focus shifts from construction (as it was for ponding) to operations, to ensure the attainment of the increased stability of dry and treated wastes. Due to the high strength of many of these wastes, the final use potential of the site is relatively broad, and it can become an economic incentive that field conditions do not interfere with material strength.

From this perspective, abnormal events are cast differently as well. They are any event which, within the scope of available planning and engineering technique, the disposal site manager cannot accommodate. For instance, during a tremendous storm, the disposal site is flooded and the available pumps cannot drain it fast enough to prevent seepage into and possibly saturation of the top layer(s) of the landfill. Other such occurrences include shortages of crucial supplies and other unusual weather problems.

Poor engineering would be defined in this case then by a lack of attention paid to field operating conditions and procedures. Such events as uncontrolled rainwater runoff entering the freshly placed wastes, wastes placed before curing or left in a position where curing is inhibited, development of thick lifts and improper compaction may all contribute to a reduction of the physical stability of the completed disposal area.

The Waterways Experiment Station [67] reported on testing of five sludges of varying sulfur content, origin and scrubber type. Fixation generally resulted in a consolidated material of increased density, decreased porosity and decreased permeability with some degree of structural strength. These results held true for processes producing a concrete-like material. Soil-like sludges produced from stabilization processes, were more porous than concrete-like sludges and raw sludges exhibiting increased permeability and decreased strength. Material properties are highly dependent on the stabilization process and were consistent for each process. Fixation was observed to have a greater effect on stabilizing double alkali sludges than limestone sludges.

The work at WES was reported on more recently by Bartos and Palermo [68]. The research indicated that fixation (stabilization) generally reduces sludge plasticity although the plasticity level of sludges is already quite low. The compressive strength is highly dependent on the process and sludge type; the strengths are typically approximate to those of soil-cement mixtures or low-strength concrete. Several of the processes produced materials comparable to low-strength concrete; one material, a stabilized western coal/limestone sludge had a compressive strength in excess of 280 kg/cm^2. The bearing capacity of soil-like stabilized sludges is comparable to low strength concrete and soil-cement type sludges should be adequate for most landfill applications. WES also found that durability is related to the stabilization process. Aerospace assessed ponding and landfill concepts for FGD wastes [60] and concluded that some control for runoff, seepage and direct discharge of water may be required.

Investigations by Thacker [56] involved the addition of fly ash to sulfite sludges. It was found that compression under load was reduced but not enough to allow the sludge to meet engineering criteria for lead bearing foundations. No time-dependent bonds were developed in fly ash-sulfite sludge. The addition of fly ash to the sulfite sludge did not produce an increase in the shear strength but did lower the strain causing shear failure. The compression of this sludge-fly ash mixture was within the range encountered in natural soils.

At the Columbus and Southern Ohio Electric Conesville Station, a thiosorbic lime FGD system produces a 30% solid mixed sludge. This sludge is stabilized by an IUCS process. This sludge was compacted to ig/cc (65 lbs/ft^3) dry density in 60-cm (24-inch) layers. Tests found that the material can bear more than 5kg/cm^2 (5 tons/ft^2). The structural capability of this material may be better than for most fills. Investigators at Aerospace [60] have found that chemically stabilized sludges may attain a high load bearing strength.

The physical stability of chemically treated FGD sludges can be evaluated by knowledge of the material's compressibility, shear strength, density, bearing capacity, consolidation characteristics and durability. While each stabilized sludge will behave uniquely, the general characteristics of soil-like and concrete-like sludges outlined above present a comprehensive data base. Further research is needed to verify these results and increase the amount of available information. An important issue which has not been investigated is the compressibility, consolidation and bearing capacity of FGC sludges in combination with other wastes in a sanitary landfill. The chemical reactions which might occur by the placement of such diverse wastes in contact could possibly have an effect on morphological and thus physical characteristics of the fill as a whole.

While some field investigations on FGD sludge durability have been performed, no attempt has been made to correlate and explain the variation between in-field physical test results for stability and laboratory analysis.

Physical blinding has been observed between FGC waste and soil layers in contact [22] which has implications for leaching at such disposal sites. Small particles of sludge fill the interstices between larger particles of natural soil, thus, lowering the permeability of the natural soil. These sludges reportedly have insignificant effective cohesion, which places an upper bound on the load they can withstand. Field values have been observed to be lower for several physical characteristics including permeability, maximum dry density and compressive strength.

Land Reclamation Issues

The major issues surrounding land reclamation of dry impoundments include:

- Revegetation potential,
- Toxicity potential of sludge substrate, and
- Suitability of disposal area for post-closure uses based on physical stability in varying climate regions.

When the land disposal options are selected, consideration of restoration must address the terrestial plant cover. In the arid and semi-arid portions of this country, plants are very sensitive and require care in selection and replanting; for instance sage brush pods must be processed through the digestive system of an animal or synthetically stressed to insure proper seed germination. Also, often the overburden topsoil is very thin (3-6 inches) and must be carefully segregated for future use in restoring the disposal site.

Revegetation of ponded areas can be used to prevent erosion of dried fine material and as a step toward reclamation of the area to other uses. TVA has initiated field testing of dewatered sludge pond revegetation. Legumes, grasses and forest tree species are being examined. Survival and growth rates are not presently available but preliminary results have indicated that: (1) the sulfite and boron content of certain limestone sludges are potentially toxic to some plant species (boron uptake has been observed); and (2) soil amendment with plant nutrients such as nitrogen and phosphorus may be required to sustain growth.

The physical stability of the disposal site would dictate the range of post-closure uses. As indicated by laboratory test results, treatment of sludge material significantly alters the bearing strength of disposed FGC waste material. Untreated FGC wastes, especially those high in sulfites, can tend to liquefy. This characteristic has caused some to report that the use of even lightweight machinery could be difficult. However, experience with test ponds by TVA has indicated that once ponds are sufficiently dewatered, lightweight equipment can be utilized [69].

Based on laboratory work, Klym and Dodd [70] report that for impoundments of untreated FGC waste, two to three feet of fill would be needed over the waste to provide a working surface, and at least an additional five feet of fill for surcharging the sludge to obtain a stable landfill [70].

However, reasonable post-closure land use decisions are difficult without better definition of the behavior of large amounts of FGC waste material through field verification.

Restrictions on post-closure land use based on physical stability need to be examined. While it appears that re-use of impounded stabilized FGC materials may be restricted to parks or other uses where low loadings or tolerance of settlement can be accomplished [71,72], greater understanding of loading capacity of large volumes (depths) of stabilized FGC materials would be useful. In other words, correlations between FGC materials and other substrates (e.g., natural soils) would provide a better understanding of land reuse possibilities.

The effects of climatic conditions on dry disposal sites also requires field verification. Long term measurements of chemical or morphological changes as a result of freeze/thaw action have not been made [72]. Similarly, field testing of the effects of inundation and drying on large volumes of FGC wastes (as in an impoundment) need to be made. While fill or cover of an impoundment with relatively impervious material has been recommended to minimize contaminant leaching, the potential effects of this approach on physical stability may need to be identified. In summary, correlations between lab tests and field behavior of soils have been dedeveloped, but such correlations do not presently exist for FGC wastes [71, 72].

Revegetation potential and especially the potential for contamination of food-chain vegetation has yet to be investigated for the broad range of FGC wastes. The amount of soil amendment and/or depth of fill required to establish vegetation, the potential for upward migration of major species and trace contaminants such as heavy metals and the incorporation of these contaminants by a wide variety of species also have yet to be investigated. Soil-waste interactions in terms of water and nutrient holding capacity could be far better understood, as well as the effects of deep root systems on cracking and permeability of large-volume FGC waste impoundments.

Limitations on post-closure uses of landfilled FGC wastes of varying characterizations have not been thoroughly investigated. In addition to physical stability issues described above, safe fill heights have yet to be established. While design charts have been published for maximum safe fill heights for certain soil types, such information has not been established for various FGC wastes[71]. Triaxial compression tests on consolidated samples, with measurement of pore water pressures would help to establish maximum safe fill height in relation to slope angle and waste shearing behavior[71]. While disposal site engineering and/or post-closure practices can likely be tailored to the bearing capacity of the wastes, the basis for these practices has yet to be fully established.

Water Quality Issues

Permeation and runoff of leachate from dry disposal is a significant issue. Discussions on permeability, leachate quality and intrinsic pollutant flux found above are also relevant to dry disposal. The dry disposal methods may have a lesser level of water quality impacts for several reasons:

- Several site management practices are feasible for dry disposal operations which are infeasible or more difficult for wet impoundments. These include grading to promote runoff, and isolation of the wastes with respect to the surrounding waters[36,61,65].
- The relative absence of free moisture initially would be expected to alter and probably reduce any first flush effect associated with the leaching of occluded waste liquor.
- Untreated sulfite-rich FGC wastes which pose a potential water related impact associated with the high COD of leachate generated under anaerobic conditions, cannot easily be dewatered to the point where dry handling is feasible. This makes the disposal option less likely for a waste type of high impact potential.

Of these considerations, the first is probably the most significant and has been discussed by Leo and Rossoff[61]. They concluded that grading to promote runoff and eliminate standing water, coupled with diversion of runoff from adjacent areas, would reduce contaminant loading from FGC waste to groundwater by an order of magnitude--compared to the reported benefits of chemical treatment.

Some field-scale evaluations of water quality impacts are in progress as presented (Table 2.14). To date, no substantive results pertaining to water-related impacts associated with dry disposal methods are available from these disposal studies. As was noted above, for pond disposal, it is unusual for field evaluation of groundwater impacts to provide substancive results within periods of less than five years because contaminant migration through wastes and soils tends to occur very slowly.

Other Considerations

With very few exceptions, the potential air quality related and biological impact issues associated with dry FGC waste disposal have received very little attention in the form of empirical research.

FGC waste landfills or dry impoundments, if designed to remain uncovered by other overburden upon closure, could be sources of some fugitive particulate emissions after disposal operations ceased. (During and shortly after disposal, even the driest FGC wastes have more than the 5 to 10% moisture content required to resist wind erosion.) This issue does not appear to be addressed by previous, ongoing or planned research, but its potential overall significance does not appear to be large relative to other issues.

Mechanisms of potential biological impact are discussed in Section 2 above. Of these that apply to dry disposal, none appear to have been studied in the past and one is currently under study. The present study concerns the revegetation potential of dewatered FGC waste ponds. It is being performed by TVA, the Aerospace Corporation, and others as part of the EPA-sponsored Shawnee Field Evaluation program. Only early results of this work are available. These are discussed in Section 4.2.2.2 above.

4.2.5 Mine Disposal

FGC waste disposal at mine sites can potentially take three forms: subterranean placement, burial in enclosed lifts and bulldozing into embankments. Each method is unique and engineering criteria vary accordingly.

Physical Stability Issues

Underground disposal requires a pumpable material for methods designed to date. Fly ash, bottom ash and raw FGC wastes may all be disposed in this fashion. Because the disposal scenario involves waste containment by bulkheads, the strength and anchorage of the bulkheads is an important engineering issue. Analysis of geologic strata as they affect secure bulkhead placement and leakage to aquifers plays a part in good engineering. Under normal conditions, the security of the waste is not threatened. If it is entirely contained, with drainage and treatment of drawn-off wastewaters performed, impacts of stability and also groundwater may be of little importance. Final land use is practically an unrelated matter and may conflict only with the pump station above ground. Abnormal events are those which would interrupt the geological integrity of the site. This presents more problems for groundwater contamination than in causing stability problems. While an earthquake shock may fracture an FGC waste containment structure and the now liquefied waste would flow through the mine, unless the mine were active, no loss of life and property would ensue. A possible result of such a failure is surface subsidence caused by the sudden release of strains built up over time around the sludge-filled cavities. This possibility is regarded as highly unlikely by some researchers [117].

General considerations discussed in Section 4.2.2.1 also apply here. In addition, the stability issues of surface mine pit disposal are the same as those for the dry disposal. Additional information will be required to correlate results of field studies with the results of lab and model tests. An unresolved issue regards the effect on stability of acid mine drainage in contact with FGC wastes. To date, this has been investigated only with respect to leachate formation. Also along this line is the stability of various combinations of fill materials in the spoil pit: FGC sludge, mine tailings, overburden, etc., which has not been studied in the lab or in the field. Because so much of the behavior of FGC waste can be attributed to the nature of the disposal site and operations, site-specific field studies are a necessity.

From an engineering standpoint, only materials which can be bulldozed and will remain on slopes without cracking or slumping are suitable for embankment disposal options. Thus far the only FGC wastes which may be so applied are those which have been stabilized or rich in sulfates. Abnormal events will be those which disturb the integrity of either the compacted waste or the underlying soil layers. In this case, events such as earthquakes, flooding and slumping due to saturation of subsurface layers from land rainfall are included.

At the Duquesne Light Company in Pennsylvania, disposal of a 5-10% solids fly ash slurry in an abandoned coal mine is taking place [41]. The slurry is pumped through a 50 cm borehole to the mine itself; the system includes three pump holes to dewater the filled areas. Concrete block dams were constructed to contain the material in the mine. No reports of the physical stability of the sludge of the sludge or of the system were made.

Surface mine disposal methods require at least dewatering and preferably the stabilization of FGC waste to avoid leachate formation and to permit reclamation to proceed upon a stable surface. Disposal will occur in layers and involve compaction techniques. The materials must be plastic enough for contouring by bulldozers. Curing must occur only after placement, therefore the timing of reclamation/stabilization activities must be carefully managed. Methods which result in level surfaces include disposal such as is being performed at Minnkota Power's Milton R.

Young Station in North Dakota, and mine pit disposal in horizontal layers.

The normal impacts of surface mine disposal options are strongly influenced by the requirements of the Surface Mine Control and Reclamation Act. Because these requirements will set lower limits on the bearing capacity of the land, determine water tables and surface runoff, the causes of instability are greatly reduced. Therefore, under normal circumstances in which these requirements are observed, stability would be assured. Abnormal events, however, are similar to those that would also affect dry disposal sites--a disruption of proper operations.

Erosion is a potentially serious question for graded disposal sites. Cured soil-like stabilized wastes would be as prone to erosion as a natural soil. A well planned disposal operation must therefore include anti-erosion techniques such as runoff control and vegetation. Subsurface information will play a role in determining good field operations. Knowledge of the material itself is critical for this disposal option. Abnormal events could disturb the integrity of the compacted waste and the underlying soil layers, or both.

Based on unconfined compressive tests [68], the performance of soil-like fixed sludges appears likely to be satisfactory in bearing capacity for embankment construction. While existing research has identified several types of treated materials suitable for use in embankments, a thorough survey of this application for sludges has not been made. The use of fly ash embankments has been studied extensively and put into actual use by the FHA. This is not true for FGD waste studies and more specific research on shear strength and consolidation characteristics of stabilized sludges in actual embankments should be performed.

Surface mine disposal methods require at least dewatering and sometimes the stabilization of FGC waste to avoid leachate formation and to permit reclamation to proceed upon a stable surface. Disposal can be expected to occur in layers and involve compaction techniques. The waste materials must be plastic enough for contouring by bulldozers. Curing must occur only after placement, therefore the timing of reclamation/stabilization activities must be carefully managed.

No studies of FGC waste disposal on surface mines have been completed. Two surface mines with on-site generating stations were disposing of FGC wastes in mine pits in late 1978. At Minnkota Power's Milton R. Young Station in North Dakota, filling of a "v-notch" with FGC waste is being conducted under an EPA-sponsored program. Physical stability and groundwater quality impacts are being studied by the University of North Dakota and Arthur D. Little, Inc. At Martin's Lake, Texas, FGC wastes are being placed in a lignite mine. Data from this program were unavailable as of December 1978. Additional information will be required to correlate results of field studies with the results of lab and model tests. An unresolved issue regards the effect of acid mine drainage, in contact with FGD wastes upon stability. To date this has been investigated only with respect to leachate formation. Also along this line is the stability of various combinations of fill materials in the spoil pit: FGC waste, mine tailings, overburden, etc., which has not been reported thoroughly in the lab or in the field.

Reclamation and Land Use

Disposal of FGC wastes in operating surface or underground mines or at abandoned mine sites would not require "new" land. The use of abandoned mines as FGC disposal sites would appear to be a potentially ideal disposal practice, especially where used to limit acid mine drainage. However, disposal in abandoned surface mines, while feasible, is space limited, especially due to the reclamation requirements of the Surface Mining Control and Reclamation Act. Disposal in underground mines may be less feasible (except perhaps in a few isolated cases) due to abandoned mine conditions.

A recent review of the feasibility of operating mines as disposal sites concluded that more than sufficient capacity existed in operating mines for the disposal of large quantities of FGC sludges. From a technical feasibility perspective, surface coal mines and underground room-and-pillar coal, limestone and lead/zinc mines were reported to offer the most promise. Coal mines were considered the most likely candidates due to capacity and frequent association with power plants.

A major difference between landfilling of FGC wastes and surface mine disposal is the ratio of sludge to overburden replacement. The issues of groundwater contamination and stability of FGC waste disposal in a surface mine are presently being examined by the University of North Dakota and Arthur D. Little, Inc. under EPA contract. Results of this program are not yet available. Essentially, however, the major public policy land use issues are the same as those discussed for dry disposal above. Slurried fly ash is being disposed of in an underground mine in Pennsylvania. Mine dewatering effluent has been reported within regulated limits for iron, pH and suspended particulates and has reportedly served to neutralize mine water to some extent.

Given SMCRA requirements, it is reasonable to assume that the degree to which the physical or chemical characteristics of FGC waste materials could affect post-mining reclamation efforts needs to be addressed. The potential for migration of FGC waste contaminants into surface soils and vegetation would be of particular concern for surface mines located in areas of prime farmland since restoration to agricultural production is a distinct possibility.

The existence of an underground mine would appear to be a more significant post-closure land use limiting issue than the disposal of FGC wastes in the mine. Three areas of investigation relevant to this disposal option are:

- The degree to which FGC wastes can ameliorate acid mine drainage,
- The long term potential for SO_2 emissions, and
- The significance, if any, of waste corrosive activity on underground supports, especially where surface stability could be affected.

None of these issues has yet been studied empirically as of this writing.

Water Quality Issues

The general discussions on water related impacts for dry disposal options also apply here. In addition, certain specific issues are important.

Deep Mines

Water related impacts associated with deep coal mine disposal of FGC wastes are extremely difficult to assess because the hydrogeology of mines is not well understood. Mine disposal is unique compared to other disposal options in that it has the potential for alleviating an unrelated environmental problem. The alkaline nature of the FGC wastes could tend to neutralize acid mine drainage while the sealing of mine voids might reduce the generation of acid mine drainage.

Lunt et al [29,38] assessed the potential impacts of disposal in deep mines. FGC wastes disposed of in deep mines would often be beneath the water table and may interact directly with groundwater. However, because of the nature of the mine environment, mine drainage migrates much more rapidly than other groundwater and often follows intricate paths through voids, fissures, etc. Furthermore, the mine environment may be aerated resulting in chemical alteration of coal mine drainage, which typically contains sulfuric acid. Total oxidizable sulfur (TOS) associated with sulfite-rich wastes is a contaminant of potential concern in leachate. The solubility of TOS in sulfite-rich FGC wastes has been investigated on a laboratory scale by Arthur D. Little, Inc. in relation to varying the Ca^{++} and Mg^{++} hardness and sulfuric acid concentration of ambient water [29,38]. Special precautions were taken to prevent the aeration of samples (to preserve dissolved sulfite). Sulfite solubility was generally reported to be about 30-70 ppm. It was found that the largest influence on sulfite solubility was the ionic strength of the background leaching solution. Sulfite solubility increased with the ionic strength in these tests.

Dissolved sulfite would pass through the geologic profile without attenuation along with the other major soluble anions in FGC waste leachate [38].

Duvel, Rapp and Atwood [63] have also performed laboratory leaching tests of FGC waste with a synthetic mine drainage solution. They observed generation of a black precipitate of iron sulfide and slightly higher trace metal concentrations with the acid leaching solution than with a distilled water leach. They discussed various mine disposal scenarios in some detail, concluding that complete sealing is necessary in order to reduce or eliminate the production of acid mine drainage. In view of the engineering difficulties associated with placing the waste in all mine voids, the feasibility of complete void sealing has not been demonstrated.

The potential effects of runoff leachate from waters voluntarily removed from deep mines containing FGC wastes (i.e., pumping to above-ground storage ponds) have yet to be studied.

Surface Mines

Dry disposal of FGC wastes in the spoil bank of surface mines presents similar water related impact potential as other dry disposal methods. Isolation of the wastes from the water table is technically feasible, and groundwater impacts from typical, well-designed, well-run operations would be expected to be relatively minor.

A field-scale study of mine disposal alternatives is underway at Square Butte, North Dakota. One emphasis is on monitoring groundwater quality. Meaningful results would not be available for some years. Disposal operations at Martin's Lake may also yield useful monitoring data. Surface impact potential is yet to be studied but is probably analogous to that for dry disposal.

Disposal on the mine pit floor, which is usually below the water table, is therefore expected to have a higher potential for groundwater impacts as described by Lunt, et al. [29,38] for several surface mine disposal scenarios. FGC wastes are being placed in "v-notches" in the Square Butte study, providing planned opportunity for monitoring of potential groundwater impacts in the future.

Other Environmental Assessment Considerations

As for other land disposal options discussed above, potential issues relating to air quality and biological impacts of FGC waste disposal in mines have been identified, but subject to no empirical research to date.

A potential for gaseous emissions (e.g., of SO_x) from initial reactions of alkaline FGC wastes with acid drainage in deep mines has been identified by Johnson and Lunt [38]. No lab or field-scale research on this subject appears to have been initiated. Biological issues for deep mine FGC waste disposal appear to be largely confined to potential impacts derived from water quality changes. No direct investigations appear to have been initiated, but the relative impact potential in already disturbed mine environments appears to be minor compared to that of surface disposal options.

Air quality and biological impact issues for surface mine disposal are similar to those discussed above for other dry disposal methods. These issues do not appear to have received research attention to date.

Mine Disposal Demonstration at Baukol-Noonan

The EPA is funding a mine disposal demonstration for FGC wastes at the Baukol-Noonan mine in Center, North Dakota. The project is being funded as a part of the EPA's ongoing evaluation of the feasibility of using the ocean and mines for disposal of FGC wastes.

The wastes placed in the mine are being generated by a 450-MW alkaline ash scrubbing system at Square Butte Electric Cooperatives (Minnkota Power) Milton R. Young Station. The Milton R. Young Station is a mine mouth power plant firing low sulfur lignite. The scrubber system using the alkalinity present in the fly ash for SO_2 removal. The fly ash is removed ahead of the scrubber system in a high efficiency electrostatic precipitator. It is then conveyed to a storage silo from which it is fed to the scrubber on demand. The wastes produced which consist of 70-85% fly ash and 15-30% calcium sulfate are dewatered by thickening and filtration to a solids content of 70-75% solids. The filter cake is loaded into dedicated 30-ton trucks for haulage to the mine.

The mine is a surface area strip mine operating with two draglines. As is convenient, wastes are placed either in the pit bottom after extraction of coal and before replacement of overburden; or in the v-notches between spoil banks prior to reclamation. Because of the residual pozzolanic activity of the ash, the wastes harden within a few days alleviating any stability problems in overburden replacment or reclamation activities.

The demonstration project involves monitoring of various sections of the mine to assess the impacts of waste disposal. The monitoring of work is being performed under the direction of the University of North Dakota with assistance and guidance by Arthur D. Little, Inc.

4.3 Ocean Disposal

4.3.1 Overview

At present, regulatory posture does not favor ocean disposal initiatives nor is ocean disposal of FGC wastes practiced. However, if it could be practiced, ocean disposal may be an attractive alternative in the future in the Northeast. In order to place this disposal option in perspective, EPA initiated assessment studies on ocean disposal at Arthur D. Little and the New England Aquarium, and is participating in conjunction with EPRI and DOE in a program at the State University of New York. To date both efforts have focused on lab-scale and very limited field-scale studies; further limited field-scale investigations are planned. Full-scale ocean disposal of FGC wastes has not taken place, limiting the basis for empirical assessments to the aforementioned studies, and making definitions of "typical" operating practices somewhat speculative.

4.3.2 Impact Assessment

The EPA-sponsored program being conducted by Arthur D. Little, Inc. has focused on aspects of the physical stability, water quality, and biological impact potentials of unstabilized FGC wastes. Results have been reported by Lunt et al. [29] and Cooper et al. [31].

Two types of lab-scale tests of physical behavior of FGC wastes in seawater have been completed in the Arthur D. Little program. The first was a series of "drop" tests to observe FGC waste behavior during descent in a seawater column. FGC wastes from direct lime processes exhibited significant cohesion effects in this series of tests, while gypsum and sulfite-rich dual alkali filter cakes exhibited far less cohesion. Mathematical modeling to field-scale based on these tests indicated a wide range of potential water column suspended solids concentrations in the immediate vicinity of descending FGC waste masses, ranging from near zero to in excess of 10,000 ppm [31].

Based on these water column studies and modeling efforts the Arthur D. Little investigators designed laboratory bioassays using free-swimming marine zooplankton and finfish reported to be relatively sensitive to suspended sediments. The results of these tests, performed at the New England Aquarium, were reported by Cooper et al. [33]:

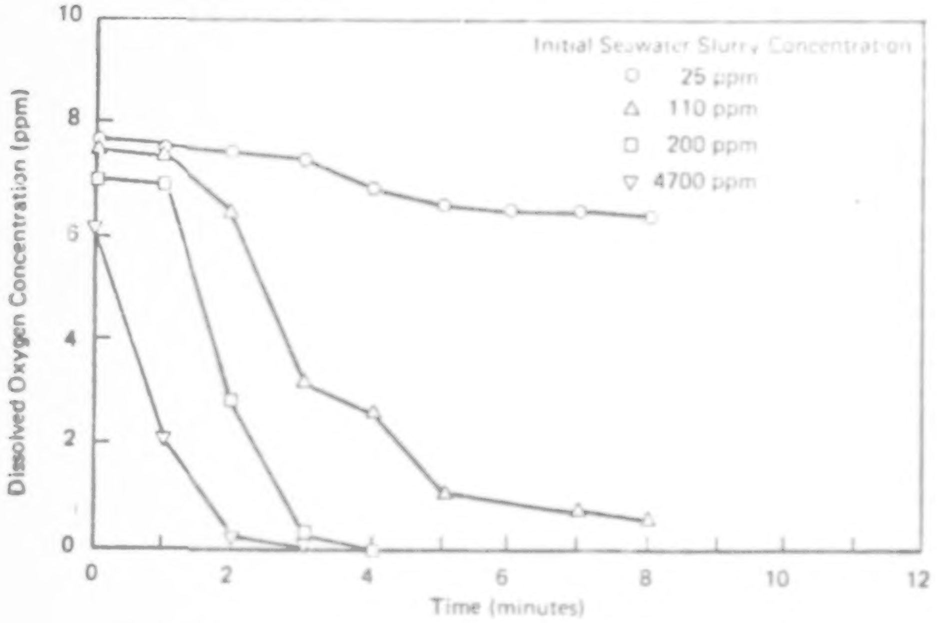
- A sulfate-rich FGC waste exhibited acute toxicity only at suspended sediment levels in excess of 1,000 ppm. These levels correspond closely to values reported for a number of very different, naturally-occurring and man-made sediments for the same organisms.
- Sulfite-rich FGC wastes exhibited high toxicity under agitated (tank-scale) mixing conditions. Oxygen depletion appeared to be the operative mechanism of toxicity. The applicability of these results at field scale is considered uncertain.

The potential for sulfite-related oxygen depletion was confirmed by a series of laboratory dissolution/oxidation studies, also reported by Cooper et al.[31]. Figure 4.1 shows the results of these tests for several direct-lime system wastes.

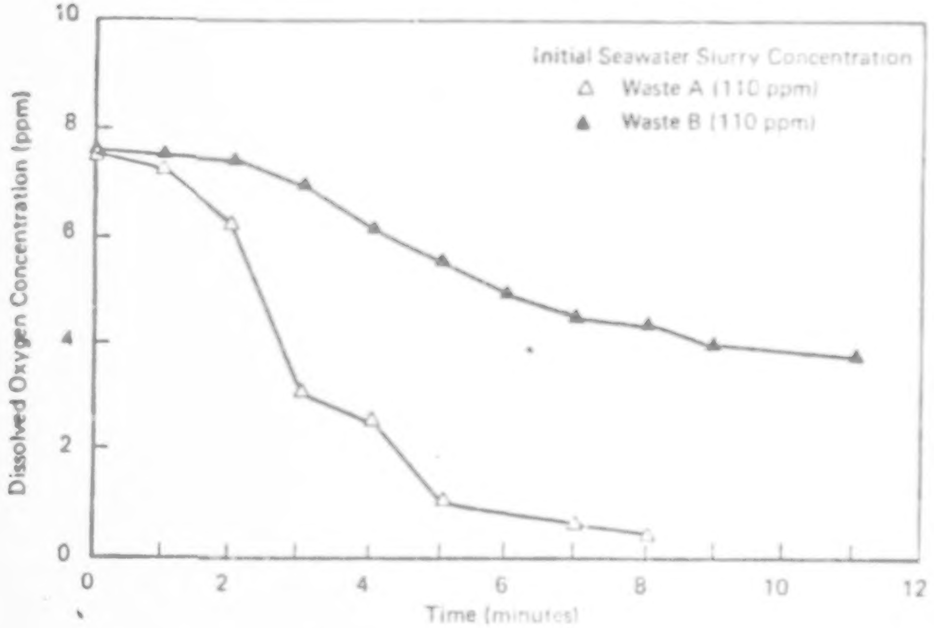
Cooper et al. [31] also reported the results of lab and limited field-scale observations of the redistribution potential of unstabilized FGC waste deposits on the ocean floor. As shown in Figure 4.2, modest currents in a shallow marine embayment were sufficient to redistribute mounds of FGC waste in less than one hour. Based on these observations and those in simulated flume tests, the Arthur D. Little investigators reported that unstabilized FGC wastes appeared to have greater redistribution potential on the ocean floor than certain clay-like soils and dredged material, and that benthic sedimentation was an impact mechanism of potential concern for unstabilized material.

Recent efforts under this program have focused on lab-scale tests to determine long-term effects of major and minor unstabilized FGC wastes on marine water quality and biota. A series of seawater leaching studies (under agitated and quiescent leaching conditions) and long-term exposure studies have been completed in 1978. Preliminary results, reported in the July through November Progress Reports for the program, indicate the following:

- Under quiescent conditions, amounts of sulfite-rich FGC waste that would be toxic (by oxygen depletion) if agitated in a closed system, can be compatible with prolonged organism survival in such a system.



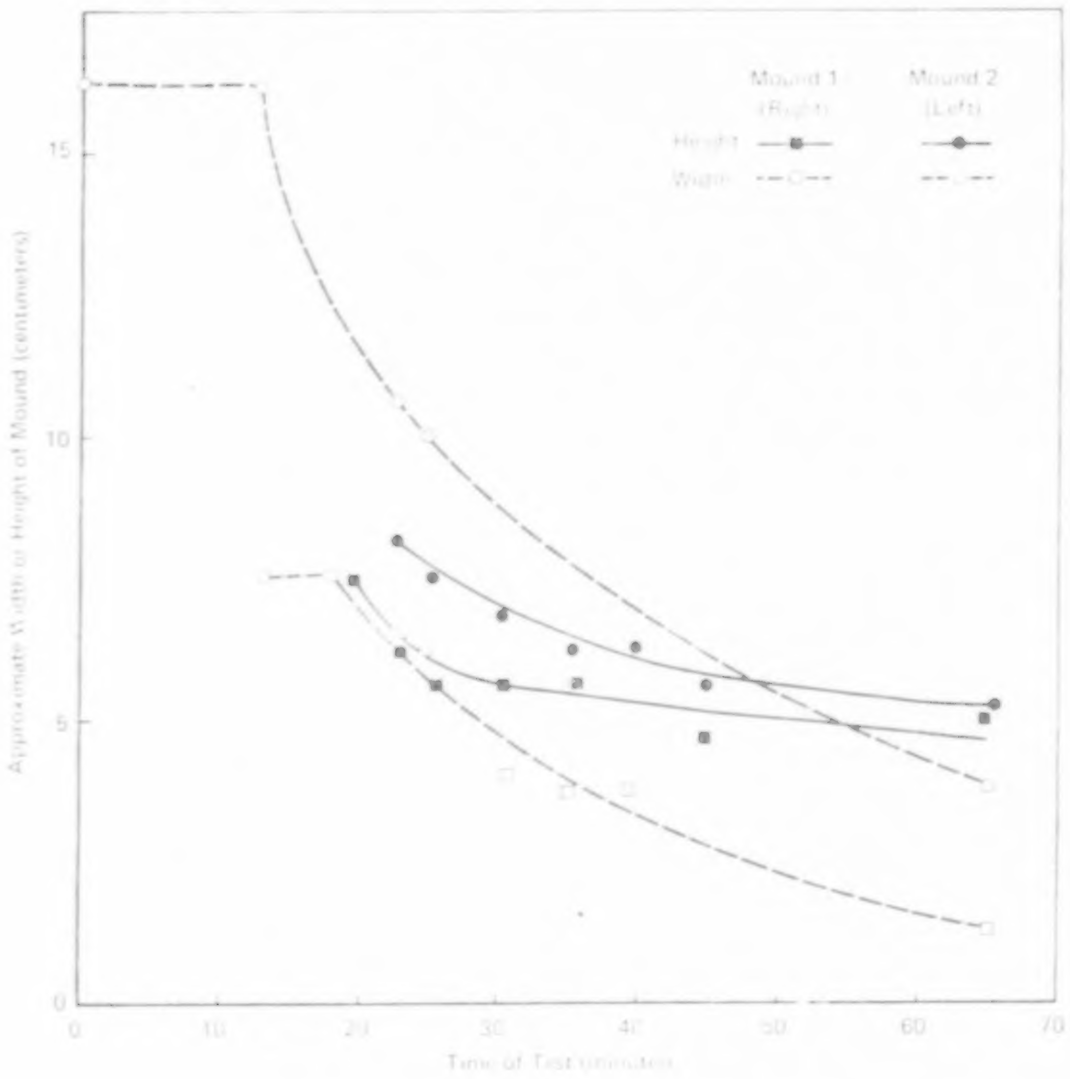
Oxygen Depletion vs. Slurry Concentration for Direct Lime Scrubber Waste



Comparative Oxygen Depletion Rates for Different Direct Lime Scrubber Wastes

Source: [31]

Figure 4.1 Oxygen Depletion Rates in Well-Agitated Slurries of FGC Wastes



Source: [31]

Figure 4.2 Observations of Mounds of FGC Wastes Created in Shallow Water Environment

- Leaching studies of Cd, Hg, Ni, Se, and Zn for several FGC wastes showed release of all but Hg under both agitated and quiescent conditions to detectable levels above those present in influent (Boston Harbor) water. For most of these metals, a correlation with the ash content of the FGC wastes appeared potentially significant.
- Exposure studies using FGC waste substrates and water column levels of metal derived from leaching tests appear to have produced potentially significant bioaccumulation of Cd, Ni and Se in invertebrate test organisms exposed for 45 days to ash-rich wastes. Control organisms and those exposed to ash-free FGD sludge do not appear to have experienced similar bioaccumulation.

Continuing work in this program is planned to focus on the following areas:

- Interpretation of the results of the leaching/exposure studies with unstabilized FGC wastes,
- Comparable studies with several stabilized wastes (to be performed by the New England Aquarium under a separate EPA Research Grant), and
- Limited field-scale studies of potential water quality and biological effects of unstabilized and stabilized wastes in a saltwater pond.

The results of the program to date appear to have reinforced initial concerns about the environmental acceptability of conventional shallow-ocean disposal (i.e., disposal on the continental shelf) of unstabilized, sulfite-rich FGC wastes; and both shallow and deep ocean conventional disposal of unstabilized FGC wastes high in ash and/or trace contaminants. On the other hand, the program appears to have reinforced the possibility for development of acceptable dispersed disposal techniques for unstabilized, sulfate-rich FGC wastes low in trace contaminants, either in shallow or deep ocean situations. Principal information gaps emerging from the results to date include:

(1) The implications of stabilization on potential sulfite and trace contaminant water quality and biological impacts, and

(2) The applicability of lab-scale results to field-scale disposal situations.

Studies of the potential for cement-like stabilized FGC wastes to be disposed of (or utilized) as artificial reefs in the shallow ocean are being conducted by the Marine Sciences Research Center of the State University of New York at Stony Brook and the IUCS Corporation. This research is being supported by several agencies and has been reported by Duedall et al. [73] and Seleginar [66].

To date, the reported results of these studies have focused on comparisons of the physical and chemical properties of the stabilized wastes with those of concrete under seawater exposure conditions. The investigators have reported favorable comparisons (for the FGC materials) from the standpoints of physical stability, trace metal leaching, initial organism colonization in an estuary, and metal uptake by colonizing organisms. However, the trace contaminant results cannot be considered definitive in the absence of comparisons with leaching accumulation reference points for non-anthropogenic substrates. Physical testing results may also be further amplified by planned testing of FGC wastes with more typical ash to sludge ratios, as the mixtures tested initially were reported to be very high in ash content.

Future work under this program is planned to focus on in-situ reef-building simulations in the shallow ocean. Water quality and biological parameters are scheduled for investigation.

4.4 Assessment of Present Control Technology

4.4.1 Introduction

It is expected that much of the difference between potential and actual impacts of the FGC waste disposal options discussed above will be determined by the degree to which presently available control technology becomes incorporated as "good design" and "good practice" in typical disposal operations. Good design and practice could also minimize the

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potential for adverse impacts from abnormal events. Scope and practice of disposal systems were discussed in Section 2.2.5. A number of control technologies have been mentioned throughout the above portions of Section 4. Some of the more important of them are summarized here.

4.4.2 Site Selection

Site selection has been discussed earlier in Section 2.5.1.1. Site selection may or may not be considered control technology. However, there is no question that proper site selection could by itself ameliorate or eliminate most of the potential disposal impacts discussed above. Site selection can be used as control technology if the mitigative combinations and impact issue categories mentioned below are considered applicable.

Potential Impact Issue	Mitigative Site Characteristics
Land Use	Proper topography, geology and hydrology; absence of nearby conflicting land uses.
Water Quality	As above for land use, plus absence of nearby sensitive receiving waters (surface or aquifers). For example, a small stream or aquifer may impose greater constraints than a large stream or impure aquifer.
Air Quality	Absence of "non-attainment area" and Class I Prevention of Significant Deterioration designations for total suspended particulates.
Biological	Absence of sensitive biological resources.

It is reasonable to assume that sites offering the greatest number of mitigative characteristics would be the best available for FGC waste disposal from an environmental standpoint, and could, in some cases, make the application of certain control techniques unnecessary that might be required at more sensitive sites. Exceptions to this generality would be sites with many advantages combined with one or more major disadvantages.

4.4.3 Waste Processing Options

In addition to judicious selection of the optimum site, the designer of an FGC waste disposal system has three waste processing options to mitigate adverse environmental impacts.

- Dewatering,
- Forced Oxidation, and
- Stabilization.

These have been discussed in Volume 3. Brief comments on their role as control technology is offered below.

4.4.3.1 Dewatering

As discussed above, dewatering of FGC waste prior to land disposal can result in major improvements in physical stability and water quality impacts due to reduced leachate migration and reduced volume of potentially contaminated overlying water (in wet impoundments). As discussed immediately above, dewatering may be particularly important in the disposal of sulfate-rich FGC wastes. Dewatering, like the disposal of relatively impermeable, stabilized wastes may require greater consideration of disposal area runoff management, in order to avoid adverse water quality effects by that route.

4.4.3.2 Forced Oxidation

The intentional production of sulfate-rich, rather than sulfite-rich FGC wastes, is presently a subject of considerable interest. In ocean disposal, the sulfate-rich products of forced oxidation would have the obvious advantage of mitigating the potential for sulfite-related depletion of dissolved oxygen. This advantage would be shared in land disposal operations (especially wet impoundments), but its relative importance is less clear. A dominant question concerning the mitigative potential of forced oxidation for land disposal is whether or not the process results in increased or decreased physical stability. Based on experience with soils, gypsum FGC wastes comprised of relatively uniform, sand-sized particles may exhibit considerable failure potential in the absence of: 1) effective compaction and dewatering, and/or 2) co-disposal with materials of varying particle size. However, if FGD gypsum is analogous to phos-gypsum, recrystallization mechanisms occurring in the disposal pile may improve stability.

4.4.3.3 Stabilization

The advantages of chemical stabilization of FGC wastes as a means of mitigating a variety of potential impacts have been discussed throughout Section 4. Stabilization processes are discussed in Volume 3. Stabilization appears to be highly relevant to the mitigation of land use issues, including the potential for abnormal events (i.e., disposal area liquefaction or other catastrophic failure modes), and the suitability of disposal sites for a broader range of post closure uses requiring increased bearing strength. Stabilization techniques resulting in decreased waste permeability can be considered mitigative of potential water quality impacts due to leachate migration. This factor can be weighed in balance on a site-specific basis with the opportunities for disposal area runoff control, since that mechanism could be of greater importance than leachate for contaminant transfer from stabilized FGC wastes. It is also unclear whether or not stabilization would reduce the overall, long-term chemical mass balance of contaminant migration from a given waste disposal area. In particular, it is not clear that reductions in long-term trace contaminant availability would take place when fly ash is used as a stabilization additive to an otherwise relatively contaminant-free FGD sludge.

Cementitious stabilization processes may also be considered mitigative of the potential for post-disposal fugitive particulate emissions from dry FGC waste disposal operations.

In ocean disposal, cementitious stabilization may remove liabilities of FGC wastes as benthic substrates and as sources of sulfite-related depletion of dissolved oxygen. However, questions of sulfite and trace contaminant availability, among others, preclude definitive judgment on this issue at this time.

4.4.4 Use of Liners

A basic option to control flow of leachates in ponding operations and generically applicable to dry disposal if site specific conditions warrant it is the use of liners. Liners are now under study at WES and by EPRI [15]; these studies were discussed in Section 2.2.1.

4.4.5 Co-disposal of Wastes and Creation of Waste/Soil Mixtures

Although the term co-disposal is often used in reference to the creation of disposal mixtures of two waste streams (e.g., FGD sludges and coal ash), it is used here to imply a broader range of opportunities. Specifically, for land disposal of FGC wastes, "co-disposal" might also include the application of technologies for the creation of soil/waste mixtures. If soils with the proper characteristics are available, the creation of soil/waste mixtures may be an alternative to the addition of fly ash where only limited increases in physical stability are desired in a disposal operation, or where trace contaminant availability needs to be reduced to facilitate revegetation or decrease water quality impacts. Traditional co-disposal involving fly ash plus FGD sludge appears to have substantial advantages over independent disposal in terms of improved physical stability and (potentially) decreased permeability. This might be especially relevant to sulfate-rich FGC wastes of uniform particle size. (See Section 4.4.4 above.) However, in some situations the extent to which the ash serves as a reservoir of certain trace contaminants could prove a liability from the standpoint of potential water quality degradation.

4.5 Summary of Data Gaps and Future Research Needs

A number of programs have been undertaken (and are in progress) by EPA, DOE, EPRI, and others. These efforts have provided much of the baseline information for environmental assessment. Provided these programs continue, additional data and insight permitting better environmental assessment will be possible.

A number of data gaps concerning FGC waste generation, characteristics, and utilization have been identified in Volumes 3 and 4.

In this subsection data gaps and research needs pertinent to environmental assessment of FGC disposal are enunciated. Data gaps apparent as of early 1979 are listed in a generally descending order of priority below.

a. Acquisition of field data on the actual impacts of full-scale disposal operations under varying environmental conditions. Field-scale monitoring of large disposal operations over a period of several years is warranted. EPRI's proposed program at Conesville Plant of Columbus and Southern Ohio Electric is one such example. EPA is also planning an extensive 2-year study on characterization and environmental monitoring of sixteen (16) full-scale utility disposal sites in support of the further development of RCRA regulations.

b. A corrollary of (a) above would be the development of correlations and tools of extrapolation to relate existing lab/pilot scale data on physical stability and water quality impacts to full-scale field data.

c. Integrated study and evaluation of the environmental trade-offs in co-disposal of various FGD wastes and various coal combustion ashes. (It appears that this type of initiative could emphasize laboratory work with limited pilot and full-scale field verification.)

d. Development of basic data (laboratory and field-scale) on the biological impact potential of principal land-based FGC waste disposal options, especially data relating to water-related impacts of major soluble species and trace contaminants. Typical questions are:

   - What are the biological and health effects of mixtures of trace metals (in the form found in liquors), such as zinc, copper, lead, mercury, cadmium or nickel in combination with selenium in particular, but also in other combinations?

- What is the uptake of potentially toxic materials by vegetation and wildlife associated with disposal areas?

- What are the levels of ambient concentration of waste-related potentially toxic materials in vegetation and surface water that may produce chronic health problems for wildlife?

The answers to these questions would help implement the "Environmentally Sensitive Areas" provisions of pending RCRA regulations. EPA is presently supporting biological testing work on FGC wastes at Oak Ridge National Laboratory.

e. Development of basic (laboratory and field) data on the potential for fugitive particulate emissions from areas previously used for the dry disposal of FGC wastes.

f. Socio-economic impacts of FGC waste disposal on land need to be better defined.

In the future, FGD waste generation will not be limited to those by utility systems. Coal utilization in industrial boilers (25 MW or larger) is also likely to grow substantially. FGD wastes from such industrial boilers (while analogous in composition to those from utility boilers) present additional waste management issues due to differences in distribution of generation facilities, in quantity of FGD wastes generated at each facility and other factors. These issues also require further evaluations and study.

5.0 REVIEW OF MONITORING CONSIDERATIONS

5.1 Regulatory Requirements for Disposal

5.1.1 Land Disposal Monitoring

Proposed regulations under the Surface Mining Control and Reclamation Act of 1977 (SMRCA) and the Resource Conservation and Recovery Act of 1976 (RCRA) contain provisions for implementing one or more kinds of environmental monitoring activities which may effect the disposal of FGC wastes in mines or impoundments.

The recently published proposed rules for a permanent regulatory program for surface coal mining and reclamation operations (30 CFR) [77] require both plans and mechanisms for implementing monitoring programs in the following areas.

- Groundwater monitoring is required of the operator for both surface and underground operations in order to ascertain whether the water quality and recharge capacity have been unduly effected by mining operations [78]. However, details of such monitoring programs, including well placement, frequency, etc. are site-specific, and will be decided by the regulating authority on a case-by-case basis, and incorporated into the reclamation plan [79]. Monitoring is continued until reclamation is complete.
- Surface water discharges must also be monitored by the operator; this is accomplished with approval from the regulating authority in conjunction with the NPDES permit requirements during mining operations [78]. However, the SMCRA surface monitoring must be continued after active mining has ceased until reclamation for post-mining uses is complete.
- Water parameters which are to be monitored and for which limits are set include pH, total iron, total manganese and total suspended solids [79]. Hydrologic parameters (i.e., flow) are also required. In addition, other parameters characteristic of the discharge may be requested by the regulator.

- Fugitive dust emissions must be monitored where required in order to show compliance with applicable air quality standards [79]

Proposed guidelines and regulations for hazardous wastes under RCRA were published in December 1978 [80]. These guidelines and regulations are now under review and may undergo significant modifications prior to scheduled promulgation in late 1979. Under these regulations (discussed more fully in Section 3) wastes will be tested to determine if they are hazardous. On the basis of such future tests, FGC wastes may be classified as non-hazardous or as a special case of hazardous wastes. However, if the initial characterization of these materials causes some of them to be classed as hazardous waste [82], then these wastes together with processing and handling operations will be subject to the following monitoring requirements:

- The waste itself is subject to an initial detailed analysis and then must be monitored on a frequent (truckload or batch) basis for at least physical appearance, specific gravity, and pH, unless the operator can demonstrate that the state of system control does not necessitate such frequency [83].
- A groundwater monitoring system, consisting of at least one well upgradient and three wells downgradient from the disposal site, must be utilized to check water quality. Sampling frequency will vary from annual to quarterly depending on water flow [84].
- Minimum analyses of groundwater samples will include conductivity, pH, chloride, total dissolved solids, organic carbon and the principal hazardous constituents or indicators found in the waste. A more comprehensive analysis including the above constituents plus beryllium, nickel, cyanide, phenols and chromatographable organics may be required [84].
- The groundwater monitoring program must be set up to continue for up to 20 years following closure of the site unless it can be shown that monitoring for that length of time is unnecessary [84].

5.1.2 Ocean Disposal Monitoring

Regulations establishing the criteria for evaluating permit applications for ocean dumping and for management of ocean disposal sites have been promulgated [85]. Part 227 deals with the criteria for the evaluation of permit applications for ocean dumping of materials, while Part 228 deals with criteria for management of the ocean disposal sites. Ocean disposal is regulated by the EPA. EPA's current policy is to discourage ocean disposal especially if alternate means of disposal are available. However, if ongoing EPA studies indicate ocean disposal is stable, the situation may change in the future. This discussion on ocean disposal monitoring is against this perspective. The following points may impact on the potential for disposal of FGC wastes.

- Where possible, bioassays employing appropriate sensitive marine organisms, rather than measurement of specific constituents, are used to assess the impacts of suspended particulate wastes [86,87].
- Each disposal site must have an impact monitoring program. Such programs may include a series of baseline and trend assessment surveys to document and assess changes at the site. Federal agencies (EPA, NOAA) will have major responsibility for these surveys. Permittees will be required to participate in the development and implementation of monitoring plans [88].
- Under Part 228.13 [88], guidelines for monitoring programs are established with respect to:

  Timing of surveys, particularly for seasonal variations;

  Duration of surveys;

  Numbers and locations of sampling stations in dump and control areas;

  Water quality test parameters, including nutrients, heavy metals, pesticides and other organic materials. In addition, "analysis for other constituents characteristic of wastes discharged ... will be included in accordance with the approved plan of study." [88];

Locations of sampling points in the water column for both chemical and biological sampling, and th number of samples;

Numbers of samples and general locations for bottom sampling for both biotic and chemical tests; and

Measurements of current and water mass measurement.

The intent and focus of the regulations is to make maximal use of biotic measurements for monitoring purposes as well as for permit approval.

5.2 Screening Tests for Solid Wastes

In keeping with an increased awareness of the need to control the disposal of wastes which may have adverse impacts on the receiving area, there is a generally recognized need for some type of screening test which can be performed on the wastes prior to disposal in order to show whether a waste meets criteria of acceptability established for a particular disposal situation. The need to conduct such tests on a periodic basis in order to monitor the quality of waste during continuing disposal operations has been addressed in part in the recent RCRA proposed regulations for hazardous wastes [83]. These regulations contain an Advanced Notice of Proposed Rulemaking, provisions of which are summarized below.

Under the RCRA proposal such screening tests for solid wastes would be comprised of three steps or operations:

- Sample pretreatment such as size reduction, physical stressing or phase separation (for wet solids) carried out prior to extraction.
- Extraction or exposure to leaching agents. Both the extraction procedure and the chemical properties of the extractant will affect the results.
- Testing of the extract (and, in some cases, the solid phase) using chemical and/or biological method.

At this time, application of such tests to FGC wastes and definition of appropriate conditions for each step are still very much in a state of flux. An ASTM/DOE collaborative program has proposed methods for leaching of waste materials [85,116]. EPA sponsored a project at Oak Ridge National

Laboratory (ORNL) to test toxicity of leaches from several wastes including FGC wastes. Preliminary results are reported [115] on a limited number of samples. Investigations are continuing and have not reached a definite stage to broadly assess whether FGC wastes are non-hazardous and under Section 4004 or special wastes under Section 3004. Lowenbach has published a comprehensive compilation of the variety of leaching test methods which have been used and proposed prior to 1978 [90].

5.2.1 Sample Pretreatment

Sample pretreatment should reflect both the form of the waste (granular, monolithic block, etc.) and anticipated stresses to which the waste may be subjected both during and after disposal (compaction, freeze-thaw, etc.). At present, significant differences which exist between test procedures are due in part to expectations of pre- and post-disposal conditions. The recent RCRA-proposed rules indicate that solids either may be ground (if necessary) to pass through a 9.5-mm standard sieve or may be subjected to specified physical stresses (multiple blows) in a "structural integrity tester" of special design [82]. An ASTM proposed leach test (from 1978) did not call for any size changes since "... The wastes used in this test shall be tested in the form in which they will be discarded" [89]. The test procedures used by IU Conversion Systems, Inc. utilize materials from real or simulated field conditions; for monolithic stabilized wastes circular slices from a standard Proctor Compactor are used [90]. It is anticipated that the public comments received by EPA on the proposed regulation for hazardous wastes will foster further discussion, and possibly aid in resolution of differences.

5.2.2 Extraction Procedure

Tests employed for FGC wastes have included both elutriation (shake tests) and column leaching procedures. Both procedures have particular advantages when properly carried out. For example, shake tests can more closely simulate surface effects as from runoff, while column leaching can more closely simulate actual percolation leaching. As yet, there is no clearly defined rationale for selecting one method over the other, and adoption of more than one method may be necessary in order to accommodate the need for various disposal mode alternative elutriation tests [90].

Likewise, the composition of the leach solution (extractant) is also under active discussion and investigation. While there appears to be a feeling that some sort of acidic solution may be appropriate, there is much controversy over the amount of acid, control of pH and the effect of the extractant on subsequent tests. The method in the proposed RCRA regulations for hazardous wastes calls for maintaining a pH of 5.0 ± 0.2 by adding a maximum of 4 milliliters of 0.5 molar acetic acid per gram (dry) of waste solids [82]. This is now under EPA review and may be modified.

ASTM/DOE program on testing coal combustion wastes is evaluating EPA and ASTM methods for extraction.

The ocean dumping regulations under MPRSA are explicit, and call for extraction of the wastes with seawater [85].

5.2.3 Testing of Extracts

In previous work, nearly all tests carried out on extracts have been chemical rather than biological, due in part to the relative difficulty of performing controlled biological tests and to the lack of standard test methods data on appropriate standards for interpretation and comparison. As discussed later in this section, this situation is changing rapidly as more biotic tests are being developed. The recently proposed RCRA tests address only a very small number of the potentially important aspects of waste biological effects, and may foster further discussion.

In general, the chemical composition of extracts is measured by the methods described below. The resulting data are most usually compared with standards for water quality, such as for drinking water.

The ocean dumping regulations under MPRSA calls for both chemical and biotic tests of the waste-seawater leachate and solid phases [85].

The Industrial Environmental Research Laboratory (Research Triangle Park) of EPA has recently initiated studies at Oak Ridge National Laboratory [46] of the applicability of the proposed RCRA extraction procedure and biological tests to FGC waste materials. The results of these studies are expected to be available in 1979. Further biological testing is also anticipated as part of the comprehensive, pending EPA-sponsored field study in support of definitive RCRA-related regulation of disposal of utility solid wastes.

5.3 Water Monitoring Methods

5.3.1 Methods for Freshwater

Included under freshwater are groundwaters and surface waters associated with landfills and mines.

5.3.1.1 Sampling Methods

An extensive compilation and comparison of methods for sampling and analysis of groundwater and surface waters at solid waste disposal sites has been published recently [91]. This manual provides an extremely useful summary of methods for siting, developing and using well arrays for groundwater monitoring. In addition, collection and pretreatment of surface waters is covered in the EPA [92] and APHA [93] manuals.

Of particular importance for FGC wastes which contain sulfites, groundwater samples intended for measurement of sulfite or dissolved oxygen must be taken and protected from atmospheric oxygen by use of a mechanical pump or a small "grab" sampler.

5.3.1.2 Analytical Methods

There are a number of manuals describing standard analytical methods and procedures which are applicable to freshwater [91,92,93]. Analytical methods are undergoing continual improvement in sensitivity as for example in the use of high-temperature furnaces and plasmas for spectroscopic measurement of metals and ion-chromatography for measurement of many trace ionic species.

5.3.1.3 On-Site Continuous Analyzers

The two major alternative approaches to the sampling and measurement of groundwater constituents involve either real-time, in-situ measurement of components of the sample stream or removal of discrete grab (or integrated) portions of the sample stream for subsequent measurement.

The in-situ measurement approach eliminates the need for sample handling (with the attendant possibility of contamination); however, the number of different monitoring devices (or "probes") is extremely limited at this time (conductivity, pH, Cl, Na and dissolved oxygen) and, in general, the long-term accuracy (drift) of those is so poor as to require frequent calibration checks. Only conductivity represents a real possibility for such monitoring and has been used frequently in groundwater monitoring programs. For disposal of FGC wastes, the predicted leaching behavior for all species suggests that concentration changes should be sufficiently slow so that continuous monitoring would not be required.

5.3.2 Methods for Ocean Monitoring

Ocean disposal is not practiced today. Current EPA policy is to discourage new ocean disposal initiatives. However, if ocean disposal is practiced in the future, monitoring of FGC ocean disposal sites can require comprehensive baseline and trend surveys covering all aspects of the ocean environment, and may include some shorter-term studies relating to dispersion ("initial mixing") of the waste immediately after dumping [80]. Because of factors such as accessibility and cost for multiple sampling points in oceanographic studies, the development of on-site continuous monitors for parameters of interest such as salinity, pH, temperature and turbidity has proceeded much farther than for equivalent groundwater tests. Still, measurements of most chemical and many biological parameters of interest, and especially those related to hazardous characteristics, must involve discrete laboratory tests.

5.3.2.1 Sampling Methods

Equipment to obtain samples of water from various depths (for example, Nansen bottle and Van Dorn samplers) and samples of bottom sediments (grab and bucket samplers as well as corers such as the Phleger) are well known and widely used in the United States [29,95].

5.3.2.2 Analytical Methods

Methods for the chemical and physical analysis of water and solids from ocean sampling have been described extensively. A survey of some state-of-the-art methods for trace level measurement of metals and organics has shown that many of the methods used in freshwater measurements can be applied, with some modifications, equally well to seawater [95].

5.3.2.3 On-Site Continuous Monitors

As noted previously, a variety of on-site monitoring devices have been developed for ocean water-column monitoring. Parameters include salinity, temperature, current velocity, pressure and turbidity [29]. Gathering such baseline data without need for active sampling and analysis may be useful for disposal and dispersal measurement for FGC wastes.

5.4 Fugitive Emissions Monitoring

Measurement and abatement of fugitive emissions as stipulated under the Clean Air Act are required under both the SMCRA (Part 816.95) and RCRA (Part 250.42-3) proposed regulations [9,77]. The ambient air measurement methods are given in 30 CFR 780.14 and include use of "Hi-Vol" samplers.

5.5 Biological Monitoring

5.5.1 Introduction

Considerations of biological monitoring for FGC waste disposal operations can be grouped into three categories:

- Baseline (pre-disposal) monitoring requirements,
- Pre-disposal bioassay testing, and
- Compliance monitoring during and after disposal operations.

In general, the use of biological monitoring as a regulatory tool is a relatively new development. Accordingly, there is little practical experience with the application of criteria and techniques discussed below. For ease of interpretation, the discussion is organized to correspond to the particular regulations that are the source of monitoring requirements in each of the three broad categories just identified.

5.5.2 Predisposal Baseline Surveys

Two bodies of federal regulations require monitoring of baseline ecology at prospective disposal sites prior to their use for disposal. These regulations are: those derived from the Surface Mining Reclamation and Control Act, and those derived from the Marine Protection Research and Sanctuaries Act. By definition, these regulations would be applicable to only two of the disposal options considered throughout this report, i.e., disposal in surface mines and disposal in the ocean.

Regulations to implement the Surface Mining Reclamation and Control Act are still emerging as of this writing. The proposed rules for the permanent regulatory program published September 18, 1978 [77] indicated that the following types of baseline biological data could be required of applicants prior to the commencement of mining operations:

- Identification and vegetative mapping of proposed vegetation reference areas, and
- Specific species inventory, habitat discussion, and protection plans for fish and wildlife resources.

Neither of these requirements would be directly related to the use of the surface mine for FGC waste disposal. Rather, they would be required of the applicant for a proposed mining operation. However, the effects of FGC waste disposal on the resources identified in this base line survey, should such disposal be practiced as part of an eventual reclamation plan, would be of relevance. Requirements for this type of post-operations survey are discussed in Section 5.5.4 below.

The final revisions of regulations and criteria for ocean dumping, published by the EPA on January 11, 1977 [85] include potential requirements for the accomplishment of extensive base line monitoring of biological parameters as part of the disposal site designation process (Section 228.4 of the regulations). Criteria to be investigated in these types of surveys are not specified in great detail by the regulations but include location in relation to breeding, nursery, feeding, or passage areas of living resources in adult or juvenile phases and potentiality for the development or recruitment of nuisance species in the disposal site. If FGC wastes were to be disposed of in an existing site, this type of monitoring requirement would not be applicable. If, however, a new site was proposed for FGC waste disposal, then such predisposal monitoring could be required. These surveys are identified as responsibilities of the federal government (EPA has primary responsibility with support from the National Oceanic and Atmospheric Administration).

5.5.3 Predisposal Bioassay Testing

Bioassay testing to measure the apparent toxicity of wastes has become an increasingly important tool in the evaluation of solid waste disposal options. In several cases, bioassay results are becoming formal considerations to complement or replace traditional measurements of potential toxicity based on physical or chemical evaluations. Four bodies of federal regulation have potential implications of this type for FGC waste disposal:

- Resource Conservation and Recovery Act,
- Toxic Substances Control Act,
- Federal Water Pollution Control Act, and
- Marine Protection Research and Sanctuaries Act.

Unlike the criteria for baseline surveys described above, requirements of bioassay testing under these regulations would be specifically applicable to FGC wastes, either on a generic or case-by-case basis.

Throughout this report the importance of the potential designation of wastes as "hazardous" under RCRA has been emphasized. The Act requires EPA to consider the toxicity and bioaccumulation potential of wastes in reaching a determination of whether or not that waste is hazardous. EPA has been developing test protocols that emphasize certain aspects of the acute and chronic toxicity of wastes, measured for specific types of organisms. More complex considerations, such as bioaccumulation and carcinogenicity, have been given less testing (and more theoretical) emphasis because of the relatively great difficulty in achieving test results that have a high degree of certainty [95]. The proposed RCRA hazardous waste guidelines published on December 18, 1978 [80, Part 250.15] list tests for mutagenicity and a theoretical estimation method for bioaccumulation which are to be applied to specific wastes (FGC not included) if an applicant wishes to demonstrate that such waste does not have adverse biological effects. The bioaccumulation estimation is one that relies on measurement of waste partition coefficients, and is more relevant to lipid-soluble organic substances than to FGC wastes. EPA has also published an advanced notice of proposed rule making [80] in which public comment is requested regarding the application of specific biological tests for toxicity including mutagenicity, DNA repair and bioaccumulation. It is not clear whether "special wastes" such as FGC wastes would be subject to these tests. This Notice proposes a few relatively standard bioassays involving the use of one type of zooplankter, and terrestrial vegetation [80]. The resolution of this type of testing requirement could have important implications for the degree of biological monitoring required of FGC wastes.

The Industrial Environmental Research Laboratory of EPA has current contract programs, both at Oak Ridge National Laboratory and at Bionetics Division of Litton Industries, to investigate the effect of FGC wastes, among other materials, on various proposed biological test systems.

ASTM Subcommittee D19.12 (Pollution Potential of Leachates from Solid Waste) is also active in the area of biological testing of solid waste extracts, and currently has two Task Groups working on mutagenicity and biological activity protocols [96].

Testing requirements under the Toxic Substances Control Act (TOSCA) could be applicable to FGC wastes in conjunction with their prospective utilization. While this is not strictly a disposal consideration, the test protocols and implications can be considered similar to those described immediately above for RCRA regulations.

Bioassay testing is assuming greater importance in the implementation of the Federal Water Pollution Control Act as emphasis moves to the regulation of "toxic" or "priority" pollutants. If effluents from FGC waste disposal operations are regulated as point-source discharges under NPDES permitting procedures, permit review agencies have the opportunity to apply bioassay tests to the effluent in addition to (and in some cases, in place of) traditional chemical analyses. To date, there has been some use of this option in federal implementation. Specifically, the regulations governing ocean outfall discharges have described acute toxicity testing requirements, coupled with possible chronic toxicity and accumulation tests. The bioassay approach is appearing in various state and local level programs as well. For example, a Colorado guideline undergoing public hearing in November 1978 allowed the use of bioassay results obtained by testing ecologically or economically important and sensitive species as an alternative to other existing effluent limitations for many toxicants. Ohio regulations indicated that all pollutants or combinations in a discharge cannot exceed one-tenth the 96-hour LC_{50} for representative aquatic species. It also includes a more stringent application factor (1/100) for persistent toxicants. As more states assume implementation responsibilities and NPDES permitting authority, the likelihood of FGC wastes undergoing aquatic bioassay evaluations is expected to increase.

The EPA ocean dumping regulations [85] require bioassay testing of "appropriate sensitive marine organisms" with candidate wastes for ocean disposal. This would include testing with representatives of phytaplankton or zooplankton, crustacean or mollusk, and fish species at the EPA's discretion. If FGC wastes are considered to have a "solid phase," similar testing with benthic organisms (filter feeders, deposit feeders, and burrowers) would also be required. The test requirements for ocean disposal are determined on a case-by-case basis, but their scope includes consideration of acute and chronic toxicity as well as bioaccumulation potential.

5.5.4 Biological Monitoring for Disposal Operation Compliance

Present regulations under three statutes define biological monitoring that would be applicable to ongoing disposal operations. The statutes are: Surface Mining Reclamation and Control Act, Federal Water Pollution Control Act, and Marine Protection Research and Sanctuaries Act.

If FGC wastes were disposed in surface mines, the effects of this disposal would be evaluated in the context of the overall mine reclamation effort. Accordingly, the types of regulations under consideration by the Department of the Interior could require continuing monitoring of the success of revegetation efforts. The proposed final rules on Surface Mining Reclamation and Enforcement Provisions [77] included a requirement to evaluate vegetative species diversity, distribution, seasonal variety and vigor. For the production of agricultural crops, the crop production on a mined area compared to that of a reference area would be evaluated. For determining compliance, production would be considered "equal" on the mined area if it equaled 90% or more of that on the reference area for a minimum of two growing seasons. Base line survey requirements for the determination of reference areas are discussed above in Section 5.5.3.

State initiatives in the enforcement of the Federal Water Pollution Control Act sometimes include biological monitoring requirements. For example, Florida measures effects on the "biological integrity" of the area receiving an effluent discharge as an alternate index on environmental impact [97]. The Florida criteria indicate that the Shannon Weaver diversity index for benthic macroinvertebrates cannot be reduced to less than 75% of background levels, determined by triplicate sampling. This type of criteria is not yet common. However, some local enforcement agencies, such as the Erie County Department of Health in Pennsylvania, use combined biological and chemical monitoring as a means of "red flagging" potential leachate problems from solid waste disposal sites. Because, in some cases, this approach may be less expensive than monitoring an increasingly long list of chemical constituents, it is reasonable to expect more enforcement agencies to consider its use.

Site monitoring during disposal operations is also a continuing responsibility of the federal government under the Marine Protection Research and Sanctuaries Act. Ocean disposal of FGC wastes would be subject to such monitoring. Biological considerations would include the following:

- Absence from the disposal site of pollution-sensitive biota characteristic of the general area, and
- Progressive, non-seasonal changes in composition or numbers of pelagic, demersal or benthic biota at or near the site.

Continued use of a disposal site could be contingent on the results of these monitoring programs [85].

Biological testing is assuming increasing importance in assessing the real environmental impacts on disposal sites, and for providing guidance on long-term genetic and toxic effects. At this time, research support is needed in the development of improved biological tests which can be applied to samples obtained from laboratory or field monitoring studies. Also of high priority is the need to establish appropriate and acceptable protocols for the predictive testing of solid wastes. Lesser priorities concern the need to support R&D field studies for testing and improving monitoring tests.

5.6 Monitoring of Physical Properties

To date virtually all of the planning and implementation of monitoring programs for FGC waste disposal has centered around the concentrations of and transport of substances which are potentially toxic or hazardous to the health of various life forms. However, the potential impacts which the physical stability of emplaced FGC wastes may have on both site operations and post-operational use of the site warrants some consideration of possible efforts to monitor appropriate physical properties. At present, there are no federal regulatory requirements for monitoring physical stability of materials involved in FGC waste disposal. Should such monitoring become desirable, the Army Corps of Engineers has established procedures for in-situ physical tests, as part of the guidelines for dam inspection, which may be appropriate for FGC materials.

In-situ measurements which may be useful in assessing stability of emplaced wastes include changes in strength and degree of saturation as a function of depth. The techniques for making these measurements are used in civil engineering programs, such as dam inspection, and may need to be brought to bear on FGC wastes in order to ascertain the extent to which these waste behave in a manner analogous to similar soils.

5.7 Post-Operational Monitoring

The type and extent of post-operational monitoring needed for FGC disposal sites will vary markedly as a function both of disposal operation and of intended end use of the land. For example, regulations governing both disposal of hazardous wastes and coal mining operations may impose quite different monitoring requirements.

Leaching of potentially harmful substances from the wastes into groundwater is expected to be a major long-term impact for any site which is not covered or otherwise rendered impervious to generation and percolation of leachate. Because of the relatively long time scale during which such leaching occurs, post-closure monitoring of groundwater in close proximity to the site for an extended period will be necessary in order to detect such effects. The proposed regulations governing disposal of hazardous wastes [80] recognize this problem, in part, by requiring that a post-closure monitoring program be maintained for a period of up to 20 years at the same level (frequency and analytical requirements) as was employed during active operations. The proposed surface mining regulations [77], which do not address FGC wastes specifically, indicate that a monitoring program, acceptable to the regulatory authority, must be maintained until the groundwater recharge capacity and quality has returned to levels stated in the permit. No limit is placed on this effort.

If disposal operations have resulted in potential disturbance to living species in the area, and these were included in predisposal baseline assessments, both for disposal in the ocean and in mines, then some form of biological monitoring would be required after operations had ceased in order to determine that the area was returned to any level of "life-support" required by the regulations.

If post-disposal land use differs from the original use, as for example, diversion to alternative agricultural purposes, then a redefinition of monitoring requirements to include biological samples, for example, would likely be required. Such changes would have to be dealt with on a case-by-case basis.

The technical details of such post-operational monitoring activities would likely resemble those utilized during operations. It would be expected that accumulation and evaluation of the operational monitoring data might allow selection of key indicator parameters or species for post-operational monitoring.

5.8 Data Gaps and Future Research Needs

FGC waste disposal practices will be subject to monitoring to the extent required by environmental regulations. As such, the principal impetus for monitoring is regulatory, and thus the needs are best described against the perspective of regulatory requirements.

Broadly speaking, biological testing and monitoring is assuming increasing importance in assessing the real environmental impacts on disposal sites, and for providing guidance on long-term genetic and toxic effects. At this time, research support is needed for the development of a broader base of improved biological tests which can be applied to samples obtained from laboratory or field monitoring studies. Also of high priority is the need to establish appropriate and acceptable protocols for the predictive testing of solid wastes. Lesser priorities concern the need to support R&D field studies for testing and improving monitoring tests.

To date, most monitoring data gathered has been derived from chemical rather than biological tests. As pointed out in Section 5, biological and bioassay tests are becoming increasingly important for assessing the real impact (as opposed to inferential impact based on chemical tests alone) on the ecology at the disposal site itself, as well as for providing some guidance as to long-term genetic and toxic effects of wastes proposed for disposal. Both of these areas are extremely important to the acceptability and eventual disposition of FGC wastes. In each of the technical areas discussed below, the needs related to biological testing are of high priority. The technical areas are:

- Indicators and Measurement Parameters - Selection of appropriate parameters and species for monitoring is the key element in any monitoring program. An understanding of the potentially hazardous characteristics of FGC wastes allow selection of candidate organisms for controlled testing. This activity is closely coupled to improvements in methodology.
- Measurement Methodology - Methods for carrying out biological tests for acute and chronic toxic and accumulation effects and for detecting genetic effects are now under active development in connection with many EPA programs in water pollution. These efforts should be supported in order to bring the state of the art in biological testing up to the level of chemical testing, in terms of applicability, sensitivity, specificity and repeatability.
- Sampling Methodology - The ability to obtain representative control and experimental samples, whether of groundwater or of species within the localized ecosystem, is essential to carrying out valid baseline and trend assessments. The major problem of predicting local groundwater flow patterns in order to plan and implement an effective groundwater sampling program, plagues FGC waste disposal in the same way as other solid waste disposal programs. Additional effort on improved methods for predicting and tracing groundwater flow is warranted now because of the rapidly expanding programs related to RCRA.
- Field R & D Programs - Additional support to ongoing and upcoming field monitoring test programs should be considered. It is especially important to include tests of appropriate biological monitoring systems in order to provide opportunities for correlation of chemical and biological data under controlled field conditions. In addition, in-situ tests of physical properties of the emplaced FGC wastes should be considered at a controlled field site. Tests of the variation of strength, density and saturation as they vary with depth of overburden and with time would be extremely valuable, not only for the correlation with laboratory tests, but also as indications of the utility of such measurement for monitoring stability.

- Relationship With Other Monitoring Programs - Recent publications have pointed up the complex interrelationships of the multitude of environmental monitoring programs presently conducted by various Federal agencies [98,99]. There is increasing need for and emphasis on obtaining valid correlations among independent systems through increased implementation of quality assurance programs, and on avoiding excessive duplication of efforts. The EPA FGC waste disposal activities and programs are at the interfaces between a number of Federal agencies and program areas, and, hence, may afford the opportunity to provide some of the needed correlative activity.

- Development of suitable and acceptable protocols for pretreatment and extraction steps for predictive tests of solid wastes is of high priority as discussed in Section 5 of this volume. Such procedures are essential for testing and qualifying FGC wastes in all forms (stabilized and unstabilized) under proposed RCRA regulations.

6.0 REVIEW OF DISPOSAL ECONOMICS

6.1 Introduction

The economics of FGC waste disposal are quickly becoming one of the most important factors in the implementation of particulate control and FGD systems. Studies of FGC process technology and evaluations of specific FGC process applications now routinely incorporate analyses of associated waste processing and disposal costs. With the increasing importance of waste disposal and the growing emphasis on environmentally sound waste disposal practices, a number of conceptual design and cost studies have also been undertaken sponsored by governmental agencies and private organizations, notably the EPA and EPRI. These studies have been basically of two types:

- First, generalized costing to develop comparative economics for various waste disposal options, including current practices and potential alternatives. Such studies have been performed by TVA [23,27,102,103,104], Aerospace [37,105-109], Michael Baker Associates [9] and ADL [29]. These have focused on FGD wastes, including stabilized wastes. Fly ash waste disposal has been studied by NUS [110] for the Utilities Water Act Group (UWAG).
- Second, economic impact analyses to estimate the effects of various FGD waste disposal regulatory scenarios on the utility industry. Two impact studies have recently been performed by Radian [111] and SCS Engineers [112]. Reports on both of these studies are now in draft form. Additional studies have been undertaken by DOE regarding the possible impact of RCRA on waste disposal costs.

In addition, site-specific and system-specific studies have been performed by a number of utilities, engineering firms and other consulting organizations. However, this assessment of the economics of waste disposal is based only on the generic studies mentioned above.

6.2 Generalized Waste Disposal Cost Studies

6.2.1 Description of Studies

6.2.1.1 Overview

Table 6.1 summarizes the general scope and cost bases for the generalized cost studies performed by TVA, Aerospace, Michael Baker

6-2

Table 6.1

Summary of General Conceptualized Cost Studies for the FGC Waste Disposal

FGD WASTES

		Type of Scrubber		Mode of Operation		Disposal Options Considered							
Contractor	Sponsor	Conv. High S	Forced Oxidation	SO_2 Only	SO_2 + Ash	Dry Landfill	Wet Pond	Surface Mine	Underground Mine	Ocean	No. Cases	Base Year	References
TVA	EPA	Limestone[a]	Limestone	✓	✓	✓	✓	✓	-	-	150+	1979/80	23, 27, 102, 103, 104
Aerospace	EPA	Limestone	Limestone	✓	(✓)[b]	✓	✓	-	-	-	~30[c]	1976&77	37, 105, 106, 107, 108, 109
Michael Baker	EPRI	Lime	-	✓	-	✓	✓	-	-	-	4	1976	9
ADL	EPA	Lime	-	✓	-	-	-	✓	✓	✓	16	1977	29
NUS	UWAG			Fly Ash Only		✓	✓	-	-	-	2	1976	110

[a] Four cases include lime scrubbing.

[b] Included only for forced oxidation.

[c] Number of cases studied varies with report.

Source: Arthur D. Little, Inc.

Associates, and Arthur D. Little. Table 6.2 gives the basic design and operating assumptions for each of these studies. Where the studies are still ongoing, the base years for the most recently published cost estimates are shown.

Unfortunately, the design and operating assumptions in these economics studies as well as the battery limits for the disposal systems differ. Also, costs are generally presented in lump sum form covering the entire waste processing and disposal facilities. Hence, direct comparisons of cost estimates are difficult at best. In this regard, efforts are now under way to develop a standard cost basis for future cost analyses of FGC systems and disposal operations prepared by EPA contractors.

In developing any generalized costs for waste disposal, it is also important to recognize the fact that it is frequently difficult to totally divorce the waste disposal system from the scrubber. This is particularly true when comparing systems with different types of ash collection or scrubber technology (e.g., forced oxidation), and it may be equally important when developing the design basis for the waste processing facilities. In most cases, waste processing will be coupled directly to FGC scrubbers or thickeners, and the waste processing plant must be capable of handling the short-term sustained peak loads expected for the FGC system itself, especially with regard to variations in coal sulfur and ash content. Such overdesign needs to be factored into either the capacity of the equipment itself and/or provision for a buffer between the FGC system and parts of the waste processing plant (such as interim storage of filter cake and ash). It is best, therefore, to evaluate waste disposal in the context of total FGC system costs rather than independently.

In addition to the generic and generalized cost studies, cost data is now beginning to be published on full-scale commercial disposal operations as new systems come on-line and more accurate accounting of waste disposal costs is employed. These cost data will be reviewed as they apply to each of the disposal methods discussed. The EPA is also funding two disposal demonstration projects which will provide additional cost information--a landfill impoundment at LG&E's Cane Run Station and a mine impoundment at the Baukol Noonan Mine in North Dakota.

Table 6.2

Summary of Basic Assumptions for General Cost Studies - FGD/FGC Wastes

	TVA				
	Base Case	Variations	Aerospace[a]	Michael Baker	ADL
POWER PLANT					
Boiler Size (No. x MW)	500	200 & 1500	1,000	2 x 500	500
Heat Rate (Btu/kWh)	9,000		9,000 & 9,300	10,000	(0.85 lb Coal/kWh)
Location	Midwestern			Eastern	Eastern
Service Life (Yrs)	30	15, 20, 25	30	30	30
Load Factor (%) - First 10 Yrs	80			75	80
- Lifetime Avg.	48		50	---	---
COAL PROPERTIES					
Sulfur Content (%)	3.5	2.0 & 5.0	3.0	3.5	3.0
Ash Content (%)	16	12 & 20	12 & 14	15	10
Heating Value (Btu/lb)	10,500		12,000 & 10,560	12,000	---
SCRUBBER SYSTEM DESIGN					
Alkali	Limestone	Lime	Limestone	Lime	Lime
Type	Conventional & Forced Oxidation		Conventional for SO_2 + Ash	Conventional	Conventional
Mode of Operation	SO_2 + Ash	SO_2 Only	Forced Oxidation for SO_2 Only	SO_2 Only	SO_2 Only
Alkali Stoichiometry	Conventional Limestone = 1.5 Limestone Forced Oxidation = 1.1 Lime = 1.1		Conventional Limestone = 1.5 & 1.25 Limestone Forced Oxid. = 1.0 & 1.5	1.10	1.10
SO_2 Removal	To 1.2 lb/MM Btu		85% & 90%	78.6%	90%
ECONOMIC FACTORS					
Cost Year	1979/80		1976 & 1977	?	1977
Capital Charge Factor	0.164	0.174, 0.179, 0.194	0.18	0.18	0.17
System Battery Limits	Waste Processing + Disposal		Waste Disposal Only	Waste Processing + Disposal	Waste Disposal Only

[a] The bases for costs varied over the course of the 5-year studies.

Source: Arthur D. Little, Inc.

6.2.1.2 TVA (FGC Wastes)

The continuing FGC waste disposal cost study being performed by TVA under contract to EPA has the widest coverage with respect to the number of different wastes and disposal options considered. A generalized computer costing model has been developed similar to that for scrubber system costing. To date, over 150 cases have been analyzed.

Thus far, two reports [23,27] and at least two papers [102, 103] have been published summarizing results of this work. The first report [23] covered the disposal of both stabilized and unstabilized wastes from conventional direct lime and limestone scrubbing systems. In this initial analysis a total of 121 variations on system design and operation were included. Four base cases were established for new 500-MW plants burning high sulfur coal (3.5% sulfur, 16% ash, and 10,500 Btu/lb heating value) fitted with direct limestone scrubbing for simultaneous SO_2 and particulate control. Each base case involved a different type of disposal: one for disposal via wet ponding of unstabilized scrubber discharge, one for wet ponding of thickened waste stabilized by Dravo's Synearth process, and two for dry impoundment of filtered wastes dewatered via the Chemfix and IUCS process. Variations on these base cases were costed to evaluate the effects of power plant size and age, coal properties, disposal site distance, scrubber process conditions, stabilization additive rates, mode of waste transport, and types of pond liners for wet ponding of unstabilized wastes. Costs were also prepared for dry impoundment of unstabilized waste.

Capital cost estimates were prepared in 1979 and first-year operating cost etimates on 1980 dollars. The economics are presented on an integrated system basis (including both waste processing and disposal) starting at the scrubber battery limits. Annual revenue requirements for the four base cases range from 0.94 mills/kWh to 2.00 mills/kWh compared with scrubber costs of 3.38 mills/kWh.

In a continuation of this study, TVA has recently completed analyses of 32 additional cases involving dry impoundment of ash blended unstabilized wastes (scrubber preceded by a high efficiency electrostatic precipitator) and combined fly ash and gypsum from forced oxidation systems with simultaneous particulate control. The draft of this report [27] is now in review; however, a summary of the results of both this and the initial study has been published [102].

This work performed by TVA has involved engineering cost estimates for generalized conceptual designs, focusing on gross effects of major parameters on waste processing and disposal economics. As such, simplifying assumptions were made with regard to the engineering properties of various different types of wastes and equipment design parameters. The properties and equipment design bases are now being reviewed and modified to more closely reflect variations in different types of wastes, and efforts are being made to provide cost estimates on a modularized basis to allow addition and deletion of processing units as appropriate. And the study is being extended to include disposal of dewatered wastes in area surface mines.

The costing model has also been used [104] to evaluate the potential cost effectiveness of employing the thickener/clarifier combination being investigated by Auburn University in place of a conventional thickener or thickener/filter combination for waste dewatering. The results indicate that potential cost savings of up to $0.75/dry ton of waste (ash + FGD) may be realized if target performance is achieved.

6.2.1.3 Aerospace (FGC Wastes)

In 1974 Aerospace [105] first began developing cost estimates for wet ponding of unstabilized wastes in lined ponds and dry impoundment of stabilized wastes as a part of its ongoing contract with EPA. Since then, these estimates have been revised and additional cost data published [37,106-109]. The latest figures were published in 1978 [113] and reflect second-quarter 1977 dollars. Costs are based upon a 1000-MW power plant burning moderately high sulfur coal (3.5%) using a lime scrubber for combined SO_2 and particulate control. For ponding, wastes are assumed to be piped directly from the scrubber to the pond. A variety of different types of ponds have been considered, including ponds with natural liners, synthetically-lined ponds, and a novel approach involving ponding with underdrainage wherein the percolate is collected and returned to the scrubber. The purpose of this latter approach is to improve the density of the settled solids and, at the same time, control leachate escape.

In 1977 [109] and 1978 [113], Aerospace also published cost estimates for producing wall-board grade gypsum from limestone forced oxidation systems to compare costs with conventional limestone scrubber waste disposal. In this case, a high efficiency electrostatic precipitator was included ahead of the scrubber for particulate removal.

Aerospace has recently begun investigating, under contract to EPA, surface disposal of gypsum. Costs of disposal are being estimated as a part of this effort.

6.2.1.4 Michael Baker Associates (FGC Wastes)

Michael Baker Associates recently completed a study of the state of the art of FGC waste treatment technology [9] for EPRI. As a part of this study, cost estimates were prepared for four cases to compare the cost of disposal of untreated wastes with corresponding stabilized materials. One pair of cases compares wet ponding of thickened wastes (unstabilized vs. stabilized via a Dravo-type process), and the other compares dry impoundment of filtered wastes (unstabilized ash blended vs. stabilized via admixture of ash and lime). The basis for the economics is two 500-MW boilers firing high sulfur eastern coal (3.5% S) equipped with high efficiency electrostatic precipitators for particulate control and conventional direct lime systems for SO_2 control. Costs were prepared battery limits at the thickener underflow with processing costs based upon vendor quotations of package systems. While not stated, it is assumed that cost estimates are in mid-1977 dollars. The incremental revenue requirements as first year costs for waste stabilization were estimated to be \$1.40/dry ton of waste (ash + FGD) for dry impoundments and \$4.00/dry ton for wet ponding.

6.2.1.5 Arthur D. Little (FGC Wastes)

As a part of an ongoing study to evaluate the feasibility of ocean and mine disposal of FGC wastes, ADL prepared general disposal cost estimates for conceptualized systems [29]. A total of 16 cases were evaluated, six for mine disposal and ten for ocean disposal. The six mine disposal cases included four involving dry impoundment in surface area coal mines and two for hydraulic backfilling of underground coal mines. The ten ocean disposal alternatives included four on-shelf disposal cases and six deep ocean disposal cases. Both stabilized and unstabilized wastes are included. Costs were prepared battery limits at the discharge of the dewatering or waste processing equipment and are presented in first quarter 1977 dollars. Revised cost estimates for the most promising options are expected to be published in early 1979.

Also, as a part of this program, a mine disposal demonstration project for FGC wastes from an alkaline ash scrubbing system is being conducted. The scrubber system is at Square Butte Electric Cooperative's (Minnkota Power) Milton R. Young Station, North Dakota; and the wastes are being returned to the Baukol Noonan mine. The cost of the full-scale disposal operation is being tracked to assess overall mine disposal economics.

6.2.1.6 NUS Study (Fly Ash)

A study was performed in 1975 by NUS for the Utility Water Act Group (UWAG) to make a comparative economic evaluation of the costs associated with a dry fly ash disposal system versus a wet system for new power plants [110]. While actual costs are highly site- and system-specific, a number of baseline assumptions were made to facilitate generic comparisons. The design basis was a 35-year plant life with a lifetime total fly ash production of 8.35×10^6 metric tons. The wet pond would require a total area of 1.35 square kilometers (340 acres) and would consist of an excavated, unlined area surrounded by 9.1-meter (30-foot) containment dikes with a 5/1 slope. The dry impoundment area was estimated to require a cleared area of 0.95 square kilometers (240 acres) where ash would be deposited to a depth of 9.1 meters (30 feet) and contained by dikes with a 5/1 slope. The cover for the wet pond would be approximately 1.5 meters (5 feet) of water; the dry impoundment would be covered by 1 meter of compacted earth. In this regard, the design/cost basis was a geographic location where annual precipitation roughly equalled evaporation, a rare occurrence for most disposal sites. Thus, only the dry impoundment area includes a rainfall treatment facility.

Based upon these assumptions and using the available data, the capital cost for the wet pond was estimated to be \$22.2 million compared with

$7.8 million for the dry impoundment (1979 dollars - escalated from 1974 costs @ 8%/yr); both included land cost at $3000/acre ($750,000/square kilometer). The annual operating cost for the dry system was also estimated to be significantly less expensive than the wet system--cost of $18.00 for wet ponding per ton versus $9.50 for dry disposal (1979 dollars). A key element in the cost of disposal is that associated with run-off treatment. However, many site-specific factors could change this and other aspects of ash disposal costs.

6.2.2 Disposal Cost Estimates for FGD/FGC Wastes

6.2.2.1 Land Disposal

Three of the four studies discussed above have dealt exclusively with land disposal of FGC wastes; the fourth, performed by Arthur D. Little, has covered both land (mine) and ocean disposal. All of these studies address applications of FGC systems to relatively high sulfur coals in eastern or midwestern locations. However, there are significant differences in the bases and assumptions for the estimates which make direct comparison of costs from different studies difficult. The most important of these are as follows:

- Battery limits vary from waste disposal facilities only to complete systems including all waste processing starting at the scrubber discharge.
- In most cases, capital and operating costs are presented on a lump sum basis for the entire system rather than broken down into modular units.
- Wide variations in plant load factors (from 48.5% to 80%) skew costs to the high side for the low load cases.
- Design assumptions relative to waste physical properties and the depth of wastes in ponds and landfills vary significantly. This can affect land requirements and disposal costs by 30% or more.
- The assumptions regarding incorporation of fly ash in the disposal of FGD where fly ash is separately collected vary in different studies.

- Different approaches have been used for incorporating land costs in the disposal estimates. In some cases, the cost of land is included in depreciable capital.
- The handling of site monitoring and land reclamation usually differ markedly in generalized cost studies; however, for the most part those considered here do not include these costs.

The effect of these differences in system design and operating assumptions can create a wide range of disposal costs for any given mode of disposal. Direct comparisons of costs from different studies, therefore, requires a complete understanding of the bases upon which the costs were prepared.

The problem of handling land costs for dry impoundment and wet ponding systems can be difficult. Consideration must be given to the type of disposal operation and the potential land use following retirement of the disposal area as well as the purchased price of the land. In some cases, it may be appropriate to include land costs as a part of depreciable capital, particularly for wet ponding of unstabilized wastes. On the other hand, land values may actually appreciate for some dry impoundment areas, depending upon locale, type of wastes impounded, and the manner of final reclamation.

Wet Ponding

The two most comprehensive studies of the cost of wet ponding of FGC wastes have been performed by TVA and Aerospace. In the TVA study a total of 68 different cases for stabilized and unstabilized wastes were evaluated covering variations in plant size and age, coal composition, waste processing, scrubber operation, distance to disposal sites, and pond lining requirements. Table 6.3 summarizes the capital and operating cost estimates for the 25 cases representing waste disposal systems on new boilers equipped with conventional direct limestone scrubbing for combined particulate and SO_2 removal. The base case for these costs involves direct discharge of scrubber slurry to an onsite clay-lined pond (1 mile from the plant). For onsite disposal of unstabilized wastes TVA's estimates of capital costs range from $24.3/kW to $49.0/kW with corresponding annual operating costs of $5.55/dry ton to $12.12/dry

Table 6.3

Summary of TVA Cost Estimates for Wet Ponding

Basis: 1979/1980 Costs
500-MW New Boiler
3.5% Sulfur, 16% Ash
Conventional Limestone Scrubbing
Simultaneous SO_2 and Particulate Removal
Scrubber Discharge Directly to Pond
FGD Scrubber Costs - Capital = $72.74/kWh
- Operating = 3.38 mills/kWh

	Capital Costs ($/kW)		Operating Costs (mills/kWh)[c]		Operating Costs ($/dry ton)[c]	
Variation Comparisons[a]	Unstabilized	Stabilized	Unstabilized	Stabilized	Unstabilized	Stabilized
Plant Size (New)						
200 MW	49.0	69.7	1.44	2.60	12.12	20.41
$\boxed{\text{500 MW}}$	34.4	48.2	0.94	1.91	8.08	15.32
1500 MW	24.3	32.2	0.64	1.36	5.55	10.87
Sulfur Content						
2.0%	26.8	38.5	0.75	1.52	9.37	17.45
$\boxed{\text{3.5\%}}$	34.4	48.2	0.94	1.91	8.08	15.32
5.0%	41.3	57.0	1.10	2.29	7.35	14.08
Pumping Distance						
$\boxed{\text{1 mile}}$	34.4	48.2	0.94	1.91	8.08	15.32
5 mile	53.7	62.0	1.58	2.32	13.61	18.57
10 mile	74.8	75.5	2.14	2.67	18.48	21.39
Thickening (35% Solids)						
1 mile	37.0	---	1.06	---	9.10	---
5 mile	49.8	---	1.48	---	12.79	---
10 mile	62.9	---	1.84	---	15.89	---
Land Availability						
$\boxed{\text{Optimal (∿20-ft depth)}}$	34.4	48.2	0.94	1.91	8.08	15.32
75% of Optimal	36.0	62.1	0.96	2.25	8.29	18.06
50% of Optimal	45.4	75.4	1.18	2.60	10.15	20.82
Settled Density						
40% Solids	40.1	---	1.07	---	11.54	---
$\boxed{\text{50\% Solids}}$	34.4	---	0.94	---	8.08	---
60% Solids	30.4	---	0.84	---	6.05	---
Lining Requirement						
Unlined	28.8	---	0.79	---	6.81	---
$\boxed{\text{Clay Lined}}$	34.4	---	0.94	---	8.08	---
Synthetic Lined ($2.50/yd^2)	46.1	---	1.21	---	10.47	---
Synthetic Lined ($4.50/yd^2)	53.4	---	1.40	---	12.07	---

[a] ☐ represents base conditions.

[b] Stabilized via Dravo's Synearth® process using 7% Calcilox®

[c] Based upon 7,000 hrs/yr operation at full load.

ton. As would be expected, the most important factors for onsite disposal are those affecting the pond size and construction requirements--e.g., quantity of wastes (sulfur content and plant size), type of lining, and solids settling properties. For example, ponding costs appear to vary to about the 0.65 capacity factor for plants in the size range of 500 to 1500 MW. For offsite disposal the cost of slurry pumping becomes significant; for distances greater than about two miles, thickening of the wastes prior to disposal is generally cost-effective.

The cost of wet ponding of stabilized wastes estimated by TVA is significantly more than that of unstabilized wastes unless lining requirements become excessive. The basis for these stabilization costs is Dravo's Synearth® process using Calcilox® as the additive. The cost of the Calcilox® is a significant factor in the overall costs. At the 7% addition rate assumed here (on total dry weight basis) the cost of the Calcilox® accounts for 15-30% of the total annual operating costs.

Analogous costs for wet ponding of unstabilized wastes have been prepared by Aerospace. The basis and assumptions for these costs are generally similar to those of a number of cases considered by TVA. In 1978 Aerospace [113] published estimates of disposal costs for wet ponding ash and FGD wastes from model direct limestone scrubbing systems on 1000-MW and 500-MW boilers firing high sulfur coal. The annual average cost for codisposal of thickened wastes in a clay-lined pond, at a distance of one mile, were estimated to be $4.89/dry ton and $6.07/dry ton for 1000-MW and 500-MW systems, respectively. For disposal in a PVC-lined pond (20-mil thickness) annual costs were estimated to be $7.25/dry ton and $9.01/dry ton for the 1000-MW and 500-MW cases, respectively. At first inspection, these costs appear reasonably close to those estimated by TVA (see Table 6.3); however, there are important differences which must be reconciled before a direct comparison can be made. Table 6.4 compares the basis for the Aerospace and TVA estimates for the 500-MW cases. The most important differences affecting the cost estimates are as follows:

- Base Year - Aerospace's costs are based in mid-1977 dollars, while TVA's costs were prepared in mid-1980 dollars.

Table 6.4

Comparison of Generalized Costs for Wet Ponding Unstabilized FGC Wastes

Basis: Plant Size - 500 MW
FGC System - Conventional Limestone Scrubbing for SO_2 and Particulate On-Site, Clay-Lined Ponds
Battery Limits - Thickener Underflow

	Aerospace	TVA
Design and Operating Assumptions		
Coal Properties = % S	3.5	3.1
% Ash	14	16
SO_2 Removal Efficiency (%)	90	78.7
Limestone Utilization (%)	80	67
Annual Operating Hours--30-yr. Avg.	4380	4250
Annual Waste Production--30-yr. Avg. (dry tons)		246,500
Waste Transport: Distance (miles)	1	1
Pipeline Location	Surface	Underground
Pond Construction: Site Preparation	Minimal	Minimal
Lining Depth (inches)	18	12
Waste Depth (feet)	30	21 and ~28
Pond Land Requirement (acres)	~310	407 and 305
Capital Cost Factors		
Base Year	mid 1977	mid 1980
Indirect Costs Included Fixed Investment		
Engineering and Fees		Varies with Alternative ~20%
Field Expense	Not Included	of Direct Costs
Contingency		~20% of (Direct + Eng. + Fees + Expenses)
Other Indirect Costs in Total Capital		
Interest During Construction		12% of Fixed Plant
Startup Allowance		10% of (Fixed Plant Less Pond Const.)
Land	$5000/acre	$3500/acre

- Handling of Land Costs - Aerospace's cost estimates include land at $5,000/acre as a part of total depreciable capital, while land costs are not depreciated in TVA's estimates.
- Pond Design - Aerospace's costs are based upon a 30-foot deep pond with and 18-inch clay liner, while TVA's costs are for 20-foot deep ponds (except for the variations on optimal space which include a 30-foot deep alternative) with a 12-inch clay liner.
- Waste Quantity - While the annual average waste quanitites of total ash and FGD wastes over the life of the plant are roughly 356,000 tons in both studies, the waste quantities used in the dollars/ton estimates differ--Aerospace's costs are based upon the 30-year average while TVA's costs are based upon the annual average for the first ten years of operation (for the costs shown in Table 6.3).
- Processing Equipment - TVA's estimates include the waste dewatering equipment (thickener, surge tank, and associated pumps and piping) as well as the pipeline and pond, while Aerospace's costs include only the pipeline and pond.
- Pipeline - Aerospace's costs are based upon pipeline built above ground while TVA has assumed an underground line.
- Indirect Capital Costs - TVA's estimates include all engineering, owner's expenses and contingency while Aerospace's estimate include no engineering or owner's expenses.

In order to provide a better comparison of the Aerospace and TVA costs, an attempt has been made to adjust the estimates for the 500-MW, clay-lined pond case by putting them on a reasonably consistent basis. Specifically, five adjustments have been made:

- Conversion of costs to 1978 dollars using an escalation factor of 8% over the period 1977 through 1980;
- Reduction in the load factor for TVA's annual costs shown in Table 6.2 from 80% to the annual 30-year average of 48%, thereby reducing the quantity of solids handled and some direct operating costs (principally power);

- Extraction of land costs from the Aerospace depreciable capital;
- Extraction of the dewatering equipment and all associated indirect costs from TVA's depreciable capital; and
- Inclusion of engineering, interest during construction, and starting in Aerospace's depreciable capital by increasing the existing capital (excluding land) by 25%.

These adjusted capital investment and operating costs resulting from these modifications are as follows:

	TVA	Aerospace
Total Capital Investment ($/kW)	28	20
Annual Average Operating Cost ($/dry ton)	11.00	6.50

On this adjusted basis, the capital and operating costs differ significantly. The biggest part of the difference in operating costs is due to the variation in capital costs.

It is interesting to compare these cost estimates with the estimate prepared by NUS for disposing of fly ash alone in an unlined pond. For an annual production rate of 262,800 tons of ash per year (compared with TVA's 246,500 tons per year annual average), NUS estimated about $16.50 per ton in 1978 dollars (converted from 1979 @ 8% per year).

Dry Disposal

In TVA's economic study of FGC waste disposal, four different types of wastes from direct lime and limestone scrubbing systems have been evaluated for dry impoundment: unstabilized wastes from simultaneous SO_2 and particulate removal; wastes from SO_2 removal blended with fly ash; stabilized wastes; and gypsum wastes from forced oxidation. Of these, only the last three can be considered to be realistic options for dry impoundment. Unstabilized wastes from conventional direct lime or limestone scrubbing systems are not easily dewatered to the point where they can be handled, placed, and compacted as a stable fill material.

Table 6.5 shows cost estimates prepared by TVA for the processing and disposal of ash blended wastes, stabilized wastes, and gypsum produced by forced oxidation. Since each of these involves a different type of

Table 6.5

Summary of TVA Estimates for Dry Impoundment Disposal Systems

Basis: Limestone Scrubbing
500-MW New Boiler
3.5% S Coal, 16% Ash

Variation Comparisons[a]	Capital Costs ($/kW)			Operating Costs (mills/kWh)			Operating Costs ($/total dry ton)		
	Ash Blending[b]	Stabilization	Gypsum[d]	Ash Blending	Stabilization	Gypsum	Ash Blending	Stabilization	Gypsum
FGC SYSTEM (500MW)	92.0	72.7	77.3	3.94	3.38	3.67	--	--	--
DISPOSAL SYSTEMS									
Sulfur Content[e]									
2.0%	14.7	18.7	9.6	0.91	1.33	0.77	11.26	15.57	9.74
3.5%	17.2	21.4	10.8	1.07	1.51	0.89	9.20	12.55	7.86
5.0%	19.1	23.9	11.8	1.20	1.77	0.93	7.88	11.29	6.45
Disposal Distance									
1 mile	17.2	21.4	10.8	1.07	1.51	0.89	9.20	12.55	7.86
5 mile	17.9	22.8	11.5	1.25	1.85	1.06	10.81	15.40	9.37
10 mile	18.7	23.8	12.0	1.39	2.14	1.22	11.96	17.73	10.80
Additive Feed									
3 wt%	--	20.6	--	--	1.43	--	--	11.96	--
4 wt%	--	21.4	--	--	1.51	--	--	12.55	--
5 wt%	--	21.5	--	--	1.57	--	--	12.95	--

[a] ☐ indicates base case condition.

[b] FGC system for ash blending includes high efficiency electrostatic precipitator.

[c] Treatment involves lime addition to mixed ash and FGD wastes.

[d] Limestone forced oxidation system for simultaneous SO_2 and particulate control.

[e] Slight adjustments in FGD costs are required to account for changes in inlet SO_2 and SO_2 removal efficiency.

scrubber operation, the costs for waste processing and disposal cannot be evaluated out of the context of the entire FGC system. Hence, TVA cost estimates for the particulate control and SO_2 scrubbing systems are also shown in Table 6.5. For the ash blending option, the cost shown for the FGC system, $92/kW, includes an electrostatic precipitator for dry ash collection. For the stabilization option, the FGC system involves simultaneous SO_2 and particulate control; consequently, the cost for gas scrubbing is considerably lower, $72.7/kW. The FGC system for producing gypsum also involves simultaneous SO_2 and particulate control; however, the additional cost of forced oxidation of the scrubbing liquor increases the capital investment to $77.3/kW. According to these estimates, the base case annual costs for these three options (@ 3.5% sulfur) rank as follows:

Forced oxidation (gypsum)	- 4.56 mills/kWh
Stabilization via lime addition	- 4.89 mills/kWh
Ash blending	- 5.01 mills/kWh

The relative rankings are a result of the assumptions regarding particulate control requirements and the superior dewatering properties of gypsum. Inclusion of electrostatic precipitators for all cases would, of course, change these rankings. It is also possible that dry ash collection and blending would be required for wastes from conventional direct scrubbing systems in high sulfur coal applications.

In a study of stabilization technology for EPRI, Michael Baker Associates compared costs for conceptualized dry impoundment disposal systems for ash blending versus stabilization. The basis for these estimates was a 1000-MW power plant (two 500-MW boilers) firing 3.5% sulfur, 15% ash coal, and equipped with a high efficiency electrostatic precipitator followed by a conventional lime scrubbing system. Based upon vendor quotations for turnkey waste processing facilities, estimated capital costs were $8.8/kW for ash blending and $9.0/kW for stabilization. Corresponding first-year annual revenue requirements were $6.90/dry ton of total wastes for ash blending and $7.70/dry ton for stabilization; the difference being almost entirely due to the cost of lime. Stabilization costs were based upon lime addition at a rate equivalent to 2% of the dry weight of FGD wastes and fly ash. Increasing lime addition by 1% would increase annual revenue requirements for stabilization by about $0.50/dry ton of total wastes. At a 3% addition rate, then, the cost of treatment would run about 20% higher than ash blending alone.

This differential is slightly lower than other estimates reported in the literature. Research Cottrell, Inc., for example, estimates the cost of treatment of wastes from a 500-MW plant firing 3% sulfur coal to be 30-35% higher than ash blending [114].

Mine Disposal

Estimates of mine disposal costs have been prepared for conceptualized systems by Arthur D. Little, Inc., as a part of its feasibility study for EPA [29]. Both surface mine and underground mine options were considered. Table 6.6 summarizes the cost estimates for the most promising of the options evaluated.

The costs were prepared for wastes from a 500-MW boiler firing 3% sulfur, 10% ash coal equipped with a high efficiency electrostatic precipitator followed by a conventional lime scrubbing system. The wastes were assumed to be filtered and treated or simply blended with ash to produce a material that could be easily handled and transported. The cost of the disposal systems shown in Table 6.7, though, does not include any waste processing. The battery limits begin at the tail end of the processing facility and include: waste transfer, storage, and loading at the plant; transport to the mine; and unloading, storage/transport, and placement at the mine. Two cases are shown for surface mine disposal; one for onsite disposal (mine-mouth power plant), and one for offsite disposal (200-mile rail haul). In both cases, wastes are dumped in the mined-out pit prior to overburden replacement. Dedicated trucks were assumed for hauling and placement; for rail haul, a charge of 1¢/ton-mile for use of the coal train returning to the mine. For underground mine disposal, only onsite disposal is shown. Thickened sludge (treated or untreated) would be piped to the mine area and pumped down through boreholes into open rooms partitioned from the active mining areas with bulkheads.

The costs for onsite (mine-mouth disposal) are estimated to be $3.00-3.50/dry ton, and $6.50/dry ton for offsite disposal in a surface

Table 6.6

Summary of Mine Disposal of FGC Wastes

Basis: 500-MW Plant
3% Sulfur, 10% Ash Coal
Annual Load Factor - 80%
90% SO_2 Control
1977 Dollars

Mine Type	Location	Transport	Capital Cost ($/kW)	Operating Costs (mills/kWh)	Operating Costs ($/dry ton)
Surface (Truck Dump)	Onsite	Truck	3.7	0.35	3.30
	Offsite	Rail	3.9	0.70[a]	6.50
Underground (Hydraulic Fill)	Onsite	Pipeline	2.1	0.35	3.20

[a] Rail haul costs assumed to be $2.00/short (wet) ton = 1¢/ton-mile.

Source: [29]

Table 6.7

Summary of Preliminary Cost Estimates for Ocean Disposal of FGC Wastes (Concentrated Bottom-Dump Disposal)

Ocean Locale	Waste Type[a]	Capital Cost ($/kW)	Operating Costs	
			(mills/kWh)	($/dry ton)
Contentintal Shelf (25 nmi)	Soil-like[b]	3.2-3.7	0.4-0.5	4.15-4.90
	Block-like	6.9-7.4	0.6-0.7	6.35-7.10
Deep Ocean (100 nmi)	Soil-like[c]	5.3-7.25	0.65-0.85	6.85-8.90
	Block-like		0.85-1.05	9.05-11.10

[a] Soil-like: Mixed fly ash and FGD waste or stabilized FGD wastes.
Block-like: Stabilized waste (assumed to be reclaimed from curing ponds)

[b] Not considered promising at this time.

[c] May only be promising for sulfate-rich wastes.

Source: [29]

mine. The difference is principally due to the cost of rail haul and the additional storage/transfer requirements for an offsite mine.

As in the case of wet ponding, an attempt was made to compare these cost estimates with those prepared by TVA for dry impoundment by adjusting the assumptions to a consistent basis. This principally involved converting the costs to a constant 1978 dollar basis and deleting waste processing facilities and costs from the TVA estimates. The adjusted mine disposal costs of roughly \$3.50/dry ton compared quite closely with the adjusted TVA estimates of \$3.50-4.00/dry ton for impoundment of ash blended and stabilized waste. It would be expected that mine disposal would be less expensive than impoundment since in most cases compaction would not be required nor would additional land costs or land reclamation be required.

TVA, as a part of its ongoing evaluation of FGC wastes disposal costs for the EPA, is now preparing generalized cost estimates for surface mine disposal for comparison with other dry impoundment options.

6.2.2.2 Ocean Disposal Costs

Ocean disposal is still in the research stage. Costs for such operations will be highly dependent on the type of wastes which can be discharged, if any, and the measures required to mitigate or avoid potential environmental impacts.

Based upon a preliminary feasibility study performed by Arthur D. Little, Inc. [29], costs were prepared for conceptualized systems representing likely disposal options. Table 6.7 summarizes the cost estimates for both deep ocean (100 nautical miles offshore) and shallow ocean (25 nautical miles offshore on the continental shelf) disposal on the East Coast. The ranges of costs shown cover the use of tug/barge combinations and self-propelled ships. For near-shore disposal, self-propelled ships are slightly less expensive than tug/barge systems (assuming a 25-nmi one-way distance), but self-propelled ships are considerably cheaper than tug/barge combinations for deep ocean disposal. As in the case of the mine disposal systems, the costs shown in Table 6.7 do not include any waste processing costs; however, the costs of recovering stabilized wastes from 30-day curing ponds (to obtain a brick-like material) are included.

It is apparent from these preliminary cost estimates that if stabilization is required for any type of ocean disposal, then the costs of deep ocean disposal may be prohibitive because of the transport distances involved. The disposal of wastes on the continental shelf, on the other hand, may be cheaper than returning wastes to an offsite mine.

Cost estimates for ocean disposal are now being updated by Arthur D. Little, Inc. for the most promising options. The State University of New York at Stoney Brook is also now conducting a study of reef construction using stabilized blocks of FGC wastes under joint industry/government funding. Additional cost data on ocean disposal are expected to result from this work.

6.3 Economic (Cost) Impact Studies

Two general economic (cost) impact analyses of FGD waste disposal regulations on the utility industry have been undertaken to date. One has been performed by Radian for EPA's Industrial Environmental Research Laboratory [111] and the other has been performed by SCS Engineers for EPA's Municipal Environmental Research Laboratory [112]. Although final reports are not available for either study, preliminary results have been issued in draft form. Because of differences in the purpose, scope, and bases for these two studies, the results are not expected to be directly comparable; however, they should give a first approximation of the effects of pending or potential future waste disposal regulations on the incremental cost of FGC waste disposal to the utility industry.

6.3.1 Radian Study

The Radian study focuses on the economic impact of RCRA under the conditions that FGC wastes (both ash and FGD wastes) are considered nonhazardous [111]. The economic evaluation is based on hypothetical enforcement scenarios using a model plant approach involving "typical" 1000-MW coal-fired plants. Eight different disposal methods for fly ash, FGD wastes, and combined FGC wastes were selected as representative of existing and future disposal practices through 1985. These are:

- Fly ash - ponding and dry landfill,

- Ash-free FGD waste - ponding of thickened or unthickened slurries and landfill of dewatered waste, and
- Combined FGC waste - ponding of thickened or unthickened slurries and landfill of dewatered waste.

Ponding or dry fill of stabilized material was not considered.

Cost estimates were then prepared for each of these options for the model plant and cost factors developed to apply these costs to the entire generating capacity assumed to be affected.

The potential impact of RCRA on existing plants was assumed to be limited to those beginning operation after 1970. It was assumed that one-half of the existing capacity starting up after 1976 would have to move their disposal sites from a current average of about 5 kilometers from the plant to about 16 kilometers (the basis for this assumption is not provided), and that all would use lined ponds or unlined dry fills. For new plants, it again was assumed that all disposal areas would be either lined ponds or unlined dry fills, and that all plants would have to increase the average distance to disposal sites from the usual 5 kilometers to about 8 kilometers in order to protect groundwaters (a shorter distance than for existing plants because increased concern in siting disposal areas would lead to better selections for newer plants). The major effects of RCRA then would be increased distances to disposal sites and the use of lined ponds and dry fills. (No linings are assumed to be required for dry fills because it is assumed that all new fills would be located in impermeable areas or areas where groundwater quality would not be in danger.)

Based upon these assumptions, it is estimated that the increase in capital investment for waste disposal due to compliance with RCRA will amount to approximately one billion dollars, or about 36%, through 1985 (in 1979 dollars). However, required annual revenue requirements (in 1979 dollars) would increase only about 5-6% or about 70 million dollars per year. Table 6.8 summarizes these cost estimates. It should be noted that these estimates do not include: sunk costs associated with moving existing disposal sites; costs for recovering wastes or reclaiming existing sites due to unacceptable groundwater contamination (or danger of it); or costs for levees to protect against pond flooding.

Table 6.8

Summary of Estimated Cost of Compliance

(Mid-1979 Dollars)

	Capital Investment Costs ($)			Revenue Requirements ($/yr)		
	Estimated Cost of Compliance with RCRA		Estimated Current with Predicted Cost - No RCRA	Estimated Cost of Compliance with RCRA		Estimated Current or Predicted Cost - No RCRA
Existing Plants* (1970-1978 Construction)	49,075,000		0	68,725,000		55,350,000
Planned and Future Facilities (1978-1985)	3,631,750,000	-	2,699,650,000	1,202,700,000	-	1,148,140,000
Total Costs	3,680,825,000	-	2,699,650,000	1,271,425,000	-	1,203,490,000
Net Costs	981,175,000			67,935,000		

*Assuming 50% out of compliance

Source: [111]

6.3.2 SCS Study

SCS Engineers has evaluated the impact of different degrees of severity of FGD waste disposal regulations on the utility industry [112]. In contrast to the Radian study, the SCS analysis does not specifically address RCRA nor does it include fly ash except where it is co-disposed with FGD wastes.

Five regulatory scenarios were considered in the SCS analysis, as follows:

1. Federal Advisory - State Legislation and Enforcement--Simple permitting, stabilization not required and not commonly used (no change from current trend in disposal practices).
2. Federal Advisory - State Legislation and Enforcement--Site-specific evaluation with stabilization sometimes required (no urban ponding).
3. General Federal Legislation - State Enforcement--Physical stabilization required, no ponding.
4. Comprehensive Federal Legislation - State Enforcement upon Approval--Chemical stabilization required in urban areas.
5. Comprehensive Federal Legislation and Enforcement - No State Involvement--Chemical stabilization universally required, specifications given for the stabilization techniques.

These five regulatory scenarios were then applied to a set of 10 model plants covering three geographical regions, three coal types, and urban and rural locations. Six disposal methods were considered: unstabilized wastes in unlined ponds; unstabilized wastes in clay-lined ponds; stabilized wastes (Dravo) in unlined ponds; dry landfill of dewatered, unstabilized wastes; dry landfill of dewatered, unstabilized wastes mixed with ash; and dry landfill of stabilized wastes (IUCS). Capital and operating costs and annual revenue requirements were then perpared for each model plant and disposal option based upon the generalized disposal cost estimates prepared by TVA (see Section 6.2), and these were applied to 1980 and 1985 projections of FGD capacity categorized according to the ten model plants.

Table 6.9 summarizes the expected average future cost (in 1980 dollars) for FGD waste disposal under each of the regulatory requirements (scenario No. 1), FGD waste disposal is expected to cost an average of 1.02 mills/kWh for capacity on line in 1980 and 0.76 mills/kWh for the total capacity on line in 1985; these correspond to projected annual revenue requirements for the on-line capacity of about $2.6 billion and $3.1 billion respectively. Increasingly more stringent regulations are expected to add from 0.007 mills/kWh (scenario No. 1) to 0.37 mills/kWh (scenario No. 5) in 1980; and from 0.008 mills/kWh (scenario No. 1) to 0.56 mills/kWh (scenario No. 5). These costs do not include the sunk cost of capital investments already made under scenario No. 1 but which are no longer useable under the more stringent regulations.

6.4 Economic Uncertainties

There are a number of uncertainties concerning FGC waste disposal that importantly affect overall disposal economics and viability of certain disposal modes. Important among these are uncertainties relating to land use/availability/cost, long-term maintenance of retired disposal sites, and the financial liability/responsibility of disposal sites. These are not data gaps in the sense that they can be readily resolved through current studies or R&D efforts; rather, they are social/technical/economic issues which will require continuing consideration and evaluation.

The issue of land use, availability, and cost can be relatively complex and will become more important with the growing implementation of nonrecovery FGC systems. One aspect of this issue is directly related to regulations--i.e., the availability of land that meets all the environmental constraints of federal and state laws, and, in particular, RCRA. This can affect not only plant siting and/or disposal distances but also the type of FGC system employed and the mode of waste disposal. There are also many facets to this issue which fall outside the realm of regulations but which can directly affect FGC waste disposal economics. These generally fall under the category of land-use planning and resource allocation, which impact

Table 6.9

Summary of Regulatory Impacts to Consumers in Mills/kWh*

Location/ Coal Type	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2		Industry Average	Percent Increase Over Scenario No. 1
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural		
Regulatory Scenario No.	For the Year 1980:											
1	.53	.61	.88	.93	1.28	1.30	1.20	.57	1.59	1.59	1.017	---
2	.80	.61	1.08	.93	1.28	1.30	1.20	.57	1.59	1.59	1.024	0.7
3	.80	.72	1.08	1.10	1.28	1.49	1.20	.88	1.59	1.59	1.136	11.7
4	1.00	.72	1.44	1.10	1.83	1.49	1.20	.88	1.59	1.59	1.190	17.1
5	1.00	1.00	1.44	1.44	1.83	1.81	1.20	1.19	1.59	1.59	1.400	37.7
Regulatory Scenario No.	For the Year 1985:											
1	.53	.55	.91	.67	1.28	1.07	.78	.57	1.59	1.59	.759	---
2	.80	.55	1.08	.67	1.28	1.07	.96	.57	1.59	1.59	.767	1.1
3	.80	.64	1.08	1.08	1.28	1.42	.96	.88	1.59	1.59	.984	29.7
4	1.00	.64	1.44	1.08	1.83	1.42	1.20	.88	1.59	1.59	1.026	35.2
5	1.00	1.00	1.44	1.44	1.83	1.81	1.20	1.19	1.59	1.59	1.321	74.2

*All amounts are in present value as of mid-1980.

Source: [112]

land valuation and may ultimately constrain the types of wastes disposed of and the manner of disposal. While land-use planning frequently may be a local issue or even site-specific, long-term regional implications of large-scale FGC waste disposal can also be important. In this regard, the most cost-effective disposal system based upon the economics of the type of FGC system and the construction of the associated waste processing and disposal facilities may not be the most desirable approach in terms of long-term land use and availability.

Long-term maintenance of retired disposal sites is related to land use and availability. The need and costs for long-term maintenance or ultimate reclamation of a site cannot be determined based upon current knowledge. It therefore remains an economic uncertainty, but one which must be given increasing consideration as more disposal systems are initiated and more information becomes available on existing sites.

An issue associated in many respects with long-term maintenance of disposal sites is that of financial liability/responsibility for both the disposal site itself and any environmental impacts resulting from the disposal operation. This is both a legal and economic question, and includes such aspects as:

- Whether a contractor for waste processing and/or disposal can assume the overall responsibility and liability of the utility;
- What the extent of liability is for not complying with regulations or for causing impacts (sociological as well as environmental) that are not within the regulatory coverage; and
- The availability, extent of coverage and cost of insurance to cover the financial liability of the utility or contractor.

Some of these questions are now being addressed, but a clear-cut resolution will be many years away, if at all.

6.5 Data Gaps

Current data gaps related to the economics of the disposal of FGC wastes include both cost information per se, as well as waste properties and disposal requirements that directly impact disposal costs. In this regard, data gaps refer to areas which could be currently addressed by government and/or industry initiatives. The most important of these are listed below.

- There is a general lack of reliable cost information from commercial operations of most types of FGC disposal. On-going and planned EPA demonstration projects should at least partially fill this gap.
- There have been no definitive studies on the disposal of wastes from dry sorbent systems and the associated costs.
- Existing physical and engineering properties data on some types of wastes are not adequate as a basis for developing design requirements needed for reliable estimates of cost-effective disposal systems. Examples include: the disposal of gypsum untreated in dry impoundments; the amount of ash and lime required for adequate stabilization of some sulfite-rich wastes; and the potential for use of well-stabilized materials as liners for dry impoundments of ash blended wastes.

REFERENCES

1. National Electric Reliability Council - Seventh Annual Review of Overall Reliability and Adequacy of North American Bulk Power Systems NECR, Research Park, Princeton, NJ, 1977.

2. 1977-1978 Electrical World Directory of Electrical Utilities. McGraw Hill Book Co., New York, NY, 1978

3. Annual Environmental Analysis Report prepared by Mitre Corporation, Conrad Research, Control Data and International Research and Technology. Report to ERDA under contract EE-01-77.0135, September 1977.

4. "EPA Industrial Boiler FGD Survey-Third Quarter 1978," PEDCo Environmental, Inc., EPA-600/7-78-052C Environmental Protection Agency, Office of Research & Development, Washington, DC, November 1978.

5. "EPA Utility FGD Survey, April-May 1978," PEDCo Environmental, Inc., EPA-600/7-78-051C Environmental Protection Agency, Office of Research & Development, Washington, DC, September 1978.

6. "Steam Electric Plant Air and Water Quality Control Data," summary report. DOE/FERC-018. Federal Energy Regulation Commission. Washington, DC, 20426, September 1978.

7. "Study of Non-hazardous Wastes from Coal-fired Electric Utilities" by B. F. Jones, J. S. Sherman, D. L. Jernigan, E. P. Hamilton III, D. M. Otlmers, Radian Corporation to EPA, Draft Report, December 15, 1978.

8. Hazardous Wastes - Proposed Guidelines & Regulations and Proposal on Identification & Listing, Federal Register, Monday, December 18, 1978, Part IV, pages 58946-59028.

9. "State of the Art of FGD Sludge Fixation," W. A. Duvel, W. R. Gallagher, R. G. Knight, C. R. Kolarg, R. J. McLaren, Michael Baker, Jr., Inc., EPRI FP-671, Project 786-1, Electric Power Research Institute, Palo Alto, California, January 1978.

10. "Survey of FGD Systems: La Cygre Station Kansas City Power & Light Company," PEDCo Environmental, Inc., EPA-600/7-78-048d, Enrivonmental Protection Agency, Office of Research & Development, Washington, DC, March 1978.

11. "Survey of Flue Gas Desulfurization Systems: St. Clair Station Detroit Edison Company," PEDCo Environmental, Inc., March 1978, EPA Report No. EPA-600/7-78-048c, Washington, DC.

12. "Eighteen Months of Operation Wash Disposal System, Bruce Mansfield Power Plant, Pennsylvania Power Company," L. W. Lobdele, E. H. Rothguss and K. H. Workmen, Presented at the FGD Symposium, Hollywood, Florida, November 8-11, 1977.

13. "Designing Large Central Stations to Meet Environmental Standards," Power, 1976 Generation Planner, p. 25-34.

14. Personal Communication from Carl Gilbert of Dravo to Chakra Santhanam, Arthur D. Little, Inc., November 1978.

15. Personal Communications from Dean Golden of EPRI to Chakra Santhanam and Richard Lunt, Arthur D. Little, Inc., January 1979 and March 1979.

16. "A Primer on Ash Handling" by Allen-Sherman Hoff Co., 1976.

17. Toland, G. C. "Gypsum Tailings Pond Design, Kimberly, British Columbia" Paper 71-I-300 at Fall meeting AIME and SME, Seattle Washington, 1971.

18. Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards, Basic Fertilizer Chemicals Segment of the Fertilizer Manufacturing Industry. EPA Document 440/1-73-011, Davy Powergass, Supt. of Documents, U.S. Government Printing Office, Washington, DC, 1973.

19. Williams R. E., Kealy, C. D., and Mink, L. L. 1973. Effects and Prevention of Leakage from Mine Tailings Ponds. Transactions, SME, AIME. Vol. 254, pp. 212-216.

20. "Sulfur Oxide Throuwaway Sludge Evaluation Panel (SOTSFP) Vol. II - Final Report - Technical Discussion. EPA-650/2-75-010b Environmental Protection Agency, April 1975.

21. Commerce Business Daily. Friday, February 16, 1979, page 1.

22. Hagerty, D. J., et al, "Engineering Properties of FGD Sludges," Proceedings of the Conference on Geotechnical Practice for Disposal of Solid Waste Materials, June 1977, American Society of Civil Engineers.

23. Barrier, J. W., et al, "Economics of Disposal of Lime-Limestone Leachate Wastes: Sludge Fly Ash Blending and Gypsum Systems." Tennessee Valley Authority under Interagency Agreement EPA-IAG-D7-E721, Environmental Protection Agency, Washington, DC, 20460. Draft report May 1978.

24. "Environmentally Acceptable Landfill from Air Quality Control System," J. C. Hass and K. Ladd, Frontiers of Power Technology Conference, October 1976.

25. "Sulfur Oxides Removal by Wet Scrubbing-Apploration to Utility Boilers" M. R. Gogineni, P. G. Maurin, Frontiers of Power Technology Conference, October 1975.

26. "Options for Treating & Disposing of Scrubber Sludge," R. W. Goodwin, R. J. Gleason, Presented at The American Power Conference 40th Meeting, Chicago, Illinois, April 24-26, 1978.

27. Barrier, J. W., H. L. Faucett, and L. J. Henson, "Economics of Disposal of Lime/Limestone Scrubbing Wastes" Tennessee Valley Authority EPA 600/7-78-023a, Environmental Protection Agency, Washington, DC, February 1976.

28. "Data Base for Standards/Regulations Development for Land Disposal of FGC Sludges" D. E. Weaver, C. J. Schmidt, J. P. Woodyear, SCS Engineers, EPA 600/7-77-118, Environmental Protection Agency, December 1977.

29. "An Evaluation of the Disposal of FGD Wastes in Mines & the Ocean - An Initial Assessment," R. R. Lunt, et al EPA-600-7-77-051 Environmental Protection Agency, Office of Research & Development, Washington, DC, 20460, May 1977.

30. Cassidy, S. M., Elements of Practical Coal Mining, Society of Mining Engineers, New York, 1973.

31. Ocean Disposal of Flue-Gas-Cleaning Wastes by C. B. Cooper, R. R. Lunt, Arthur D. Little, Inc., and J. W. Jones, Environmental Protection Agency. Presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, Texas, June 25-30, 1978.

32. Duedall, I. L., et al, "Environmental Assessment of Coal Waste Disposal in the Ocean Waters," Marine Sciences Research Center, State University of New York and IU Conversion Systems, submitted to the EPA, July, 1978.

33. Hazardous Waste Guidelines and Regulations--Criteria, Identification, and Listing of Hazardous Waste, U.S. Environmental Protection Agency, 40 CFR 250 (draft), March 24, 1978.

34. Waste Discharge Requirements for Non-Sewerable Waste Disposal to Land, California State Water Resources Control Board, January 1978.

35. "Executive Summary - The Solid Waste Impact of Controlling SO_2 Emissions from Coal Fired Steam Generators," P. P. Leo and J. Rossoff, Aerospace Corporation under EPA Contract 68-01-3528 Environmental Protection AGency, Washington, DC, 20460, October 1977.

36. Flue Gas Desulfurization Waste Disposal Field Study at the Shawnee Power Station, prepared by P. P. Leo et al, Aerospace Corporation. Presented at EPA FGC Symposium, Hollywood, Florida, November 8-11, 1978.

37. Disposal of By-Products From Nonregenerable Flue Gas Desulfurization Systems: Final Report (Rough Draft), by J. Rossoff, R. C. Rossi, R. B. Fling, W. M. Graven, and P. P. Leo, Aerospace Corporation. EPA Contract No. 68-02-1010 Environmental Protection Agency, Office of Research & Development, Washington, DC 20460, March 1978.

38. "Mine Disposal of FGD Waste," Sandra L. Johnson and Richard R. Lunt, Arthur D. Little. Presented at FGD Symposium, Hollywood, Florida, November 8-11, 1977.

39. Landfill and Ponding Concepts for FGD Sludge Disposal, by J. Rossoff, P. P. Leo and R. B. Fling, Aerospace Corporation, California. Presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, Texas, June 25-30, 1978.

40. The Environmental Effects of Trace Elements in the Pond Disposal of Ash and Flue Gas Desulfurization Sludge by Radian Corporation for Electric Power Research Institute - Final Report September 1975.

41. "State of the Art Review of FGD Sludge Stabilization Using Lime/Fly Ash Admixtures," D. Weeter. Presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, Texas, June 25-30, 1978.

42. Theis, T. P. L., The Potential Trace Material Contamination of Water Resources Through the Disposal of Fly Ash", for presentation at the Second National Conference on Complete Water Reuse, Chicago, Illinois, May 4-8, 1975. CONF 750530-3.

43. The Status of Flue Gas Desulfurization Application in the United States: A Technological Assessment, U. S. Federal Power Commission, July 1977.

44. Haas, J. C., and K. L. Ladd, "Environmentally Acceptable Landfill from Air Quality Control System Sludge", Paper presented at the Frontiers of Power Technology Conference, Oklahoma State University, Stillwater, Oklahoma, 1974.

45. "Draft Economic Impact Analysis Subtitle C, Resource Conservation and Recovery Act of 1976" Arthur D. Little, Inc., Office of Solid Wastes, U.S. Environmental Protection Agency, Washington, DC, January 1979.

46. Work in Progress "Toxicity of Leachate," Oak Ridge National Laboratory, Biology Division. Contact No. 78-DX--37x. Environmental Protection Agency, IERL, Research Triangle Panc. NC, 2771.

47. Personal Communication. Julian W. Jones, EPA-IERC to Chakra Santhanam, Arthur D. Little, January 1979.

48. "The Impact of RCRA (PL 94-580) on Utility Solid Wastes" Hart F. C. & DeLaney, B. T., Fred Hart Associates EPRI FP-878, TPS 78-779, Final Report Electric Power Research Institute. Palo Alto, California, 94303, August 1978.

49. Development Document for Effluent Limitation Guidelines & New Source Performance Standards for the Steam Electric Power Generating-Point Source category EPA 440/1-74-029a Group I Environmental Protection Agency, Washington, DC, 20460, October 1976.

50. Landfill and Ponding Concepts for FGD Sludge Disposal by the Aerospace Corporation. Presented at the U.S. EPA IERL Industry Briefing Conference on Technology for Lime/Simestone Wet Scrubbing, August 29, 1978.

51. Federal Register, Vol. 43, No. 92, Thursday, May 18, 1978.

52. White House Press Release, Washington, DC, December 2, 1977.

53. Federal Register, Vol. 39, 39 FR 42510, December 5, 1974.

54. Disposition of Wastes from Stack Gas Sulfur Dioxide Removal Processes, by D. J. Hagerty, et al, University of Louisville, Report to Institute for Mining and Minerals Research, January 1, 1976.

55. Lime/Limestone Scrubbing Sludge Characterization--Shawnee Test Facility by TVA. EPA-600/7-77-123, Environmental Protection Agency Office of Resource and Development, Washington, DC, 20460, October 1977.

56. Geotechnical Properties of Flue Gas Desulfurization Sludges by Barry K. Thacker, University of Louisville, A Thesis submitted to the Faculty of the University of Louisville Speed Scientific School, May 1977.

57. Disposal and Uses of Power Plant Ash in Urban Area, P. G. Sikes and H. J. Kolbeck, Journal of the Power Division, 9,741, ASCE, May 1973, pp 217-234.

58. "Physical and Chemical Characteristics of Fly Ash and Scrubber Sludge from Some Low-Rank Western Coals", by H. Ness, A. Volesky, and S. Johnson, U. S. Department of Energy, presented at the Ash Management Conference, Texas A&M, September 25-27, 1978.

59. "FGD Waste Disposal Effective Despite Surprises," K. H. Workmen and E. H. Rothguss, Power Engineering, November 1978, pp 60-63.

60. Disposal of FLue Gass Cleaning Wastes: EPA Shawnee Field Evaluation--Second Annual Report, March 1977, by R. B. Fling, W. M. Graven, R. C. Rossi, and J. Rossoff, Aerospace Corporation, Los Angeles, California, EPA Contract No. 68-02-1010.

61. The Solid Waste Impact of Controlling SO_2 Emissions from Coal-Fired Steam Generators Volume II: Technical Discussion, by P. P. Leo and J. Rossoff, Aerospace Corporation, EPA Contract No. 68-01-3528 Work Assignment No. 6.

62. Chemical Properties and Leachate Characteristics of FGD Sludges, by J. L. Mahloch, Environmental Effects Lab., U.S. Army Engineer Waterways Experiment Station, Miss. Presented at AIChE Symposium, August 29-September 1, 1976, Atlantic City, NJ.

63. Leachate from Disposal of FGD Sludge in Deep Mines, by W. A. Duvel, Jr., J. R. Rapp and R. A. Atwood, Michael Baker, Jr., Inc. Presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, Texas, June 25-30, 1978.

64. Full-Scale FGD WAste Disposal at the Columbus and Southern Ohio Electric's Conesville Station, prepared by Danny L. Boston and James E. Martin, Columbus and Southern Ohio Electric Company, 1977.

65. Personal Communication, Carl Labowitz fo Dravo to Chakra Santhanam of Arthur D. Little, November 1978.

66. Seleginar, James David, "Chemical & Physical Behavior of Stabilized Scrubber Wastes and Fly Ash in Seawater," Masters Thesis, Marine Sciences Program, State University of New York at Story Brook, January 1978.

67. Chemical Fixation of FGD Sludges - Physical and Chemical Properties, by Jerome Mahloch, Environmental Effects Lab., U.S. Arm Engg. Waterways Experiment Station, Vicksburg, Miss., 1977.

68. PHysical and Engineering Properties of Hazardous Industrial Wastes and Sludges, by M. J. Bartos, Jr. and Mr. R. Palermo, U.S. Army Engineer Waterways Experiment Station, under EPA Contract No. IAG-D4-0569, August 1977.

69. Solid Wastes from Coal-Fired Power PLants: Use or Disposal on Agricultural Lands, G. L. Terman, Tennessee Valley Authority, National Fertilizer Center, June 1978 and Personal Communication, Paul Giordano, TVA.

70. Klym, T. W. and D. J. Dodd, "Landfill Disposal of Scrubber Sludge." Paper presented at the National ASCE Environmental Engineering Meeting, Kansas City, Mo., October 1974.

71. Peck, R.B., W. H. Hanson and T. H. Thorburn, Foundation Engineering, John Wiley & Sons, New York, 1973.

72. Van Ness, et al, "Field Studies in Disposal of Air Quality Control System Wastes." (no reference)

73. Duedall, Iver W., Harold B. O'Connors, Jr., Jeffrey H. Parker, Frank E. Roethel, and James D. Seleginar, "A Preliminary Investigation of the Composition, Physical and Chemical Behaviors and Biological Effects of Stabilized Coal-Fired Power Plant Wastes (SCPW) in the Marine Environment - A Final Report." Prepared for New York Energy Research & Development Administration, by Marine Sciences Research Center, State University of New York, Story Brook, New York, November 21, 1977.

74. Hydraulic Disposal to Mines, prepared by Nelson R. Tonet, Duquesne Light. Presented at ASME-IEEE Joint Power Generation Conference, Pittsburgh, September 27 - October 1, 1970.

75. "Study of the Use of Lime/Limestone Flue Gas Desulfurization Sludge in Underground Mines Subsidence Prevention", Work by Radian Corporation for the U. S. Bureau of Mines, Department of Interior, Washington, D. C., 1975.

76. "Feasibility Study Underground Coal Mine Drainage Abatement and Subsistence Control Using FGD Wastes", W. A. Duvel, D. W. Hupe, D. A. Palomer, and R. J. McLaren, Michael Baker, Inc. Report to EPA-IERL, Cincinnati, Ohio 45268, Draft Report, May 1978.

77. "Surface Coal Mining and Reclamation Operations, Proposed Rules for Permanent Regulatory Programs," Federal Register, Vol. 43, No. 181, September 18, 1978, p. 41661-41940.

77. "Surface Coal Mining and Reclamation Operations, Proposed Rules for Permanent REgulatory Programs," Federal Register, Vol. 43, No. 181, September 18, 1978, p. 41661-41940.

78. Ibid., p. 41887 (Part 816.52) and p. 41907 (Part 816,52).

79. Ibid., p. 41751, p. 41843 (Part 780.21), p. 41894 (Part 816.95).

80. Hazardous Waste Guidelines and Regulations," Federal Register, Vol 43, No. 243, December 18, 1978, p. 58945-59022.

81. Ibid. p. 59015 (Part 250.46-2), pp. 58991-2.

82. Ibid, p. 58956 (Part 250.13 [d]).

83. Ibid, p. 59000 (Part 250.43 [f,h]).

84. Ibid, p. 59004-6 (Part 250.43.7, .43-8).

85. Ocean Dumping, Parts 227 and 228, Federal Register, Vol. 42, No. 7, 1977.

86. Ibid, p. 2477-8 (Part 227.5).

87. Ibid, p. 2466.

88. Ibid, pp. 2487-9 (Part 228.13).

89. "Proposed Methods for Leaching of Waste Materials", American Society for Testing and Materials, Philadelphia, PA, Committee D-19, May 1978.

90. Lowenbach, William, "Compilation and Evaluation of Leaching Test Methods," U.S. Environmental Protection Agency Report EPA-600/2-780-095, May 1978.

91. Fenn, D., E. Cocozza, J. Isbister, O. Braids, B. Yare, P. Roux and B. Vincent, "Procedures Manual for Ground Water Monitoring at Solid Waste Disposal Facilities," U.S. Environmental Protection Agency Report, EPA-530/SW-611, August 1978.

92. "Manual of Methods for Chemical Analysis of Water and Wastes," U.S. Environmental Protection Agency Report EPA-625-16-74-003, 1974.

93. "Standard Methods for the Examination of Water and Wastewater," American Public Health Service, Washington, DC, 13th Edition, 1971.

94. Gibb, T. R. P., (ed), "Analytical Methods in Oceanography," American Chemical Society, Advances in Chemistry Series 147, (1975).

95. Chemical Week, December 6, 1978.

96. ASTM D19.12, Draft Proposed Standard Protocol for Acute Fish Toxicity Bioassay and Draft Proposed Salmonella/Mammalian-Minosome Mutagenesis Assay for Complex Environmental Mixtures, presented at meeting of D19.12, American Society for Testing & Materials, Philadelphia, PA, October 24, 1978

97. Personal Communication, Florida Department of Environmental Regulation to Sarah Bysshe, Arthur D. Little, Inc. 1978.

98. Morgan, G. B., "Energy Resource Development: The Monitoring Components," Environmental Sci. Tech. 12, 34-43 (1978).

99. Miller, S., "Federal Environmental Monitoring: Will the Bubble Burst?" Environmental Sci. Tech. 12,1264-1269 (1978).

100. Frascino, P. J. and Vail, D. L. "Utility Ash Disposal - State of the Art" Proceedings of the IV Ash Utilization Symposium, St. Louis, Mo., March 24-25, 1976.

101. "A Procedure for Evaluation of Environmental Impact," Leopold, L. B., et al. Circular 645, U.S. Geological Survey, Washington, D.C., 1971.

102. Barrier, J. W., "Comparative Economics of FGD Waste Disposal," EPA Industry Briefing Conference, August 1978.

103. Barrier, J. W., H. L. Faucett, and L. J. Henson, "Economics of FGD Waste Disposal," U.S. Environmental Protection Agency Report, EPA-600/7-78-058a, March 1978.

104. Barrier, J. W., "Economics for Auburn Study of Sludge Dewatering Equipment," A Report to H. L. Faucett, TVA, September 1978.

105. Rossoff, J. and R. C. Rossi, "Disposal of By-Products fron Non-Regenerable Flue Gas Desulfurization Systems: Initial Report," U. S. Environmental Protection Agency Report, EPA-650/2-74/037a, May, 1974.

106. Rossoff, J. and R. C. Rossi, "Flue Gas Cleaning Waste Disposal EPA Shawnee Field Evaluation," presented at the EPA Flue Gas Desulfurization Symposium, New Orleans, L.A., March 1976.

107. Rossoff, J., et al., "Disposal of By-Products from Non-Regenerable Flue Gas Desulfurization Systems: A Status Report," Presented at the EPA Flue Gas Desulfurization Symposium, Atlanta, GA, November 1974.

108. Rossoff, J., et al, "Disposal of By-Products from Non-Regenerable Flue Gas Desulfurization Systems: Second Progress Report," U.S. Environmental Protection Agency Report, EPA-600/7-77-052, May 1977.

109. Rossoff, J., et al, "Disposal of By-Products from Non-Regenerable Flue Gas Desulfurization Systems: Final Report," U.S. Environmental Protection Agency Report (Draft), March 1978.

110. Atwood, K. E. and Greenway, W. R. "Fly Ash Handling Systems Study Relating to Steam Electric Power Generating Point Source Category - Effluent Guidelines and Standards" prepared by C. W. Rice Division of NUS Corporation to the Utility Water Act Group (UWAG) July 1975.

111. Jones, B. F., et al, Radian Corporation, "Study of Non-Hazardous Wastes from Coal-Fired Electric Utilities", DCN 200-187-41-08 Report to EPA-IERL, Research Triangle Park, NC 27711, Draft Final Report, December 15, 1979.

112. SCS Engineers "Economic Impact of Alternative Flue Gas Desulfurization (FGD) Sludge Disposal Regulations in the Utility Industry" Report to EPA Municipal Environmental Research Laboratories, Cincinnati, Ohio. Draft Final Report, January 1979.

113. Leo, P. L. and J. Rossoff, Aerospace Corporation, "Controlling SO_2 Emissions from Coal-Fired Steam-Electric Generators: Solid Waste Impact," Two Volumes, EPA Report No. EPA-600/7-78-044a and b. Environmental Protection Agency, Washington, D. C., 20460, 1978.

114. Goodwin, R. W. and R. J. Gleason, "Options for Treating and Disposing of Scrubber Sludge," Combustion, October 1978.

115 Epton, J. L. and Larimer, F. W., Interim Report on "Toxicity of Leachates". ORNL, Oak Ridge, Tnn. Draft Report, January 21, 1979.

116. Personal Communication, John Munick, ASTM to C.J. Santhanam, Arthur D. Little, Inc., February 1979.

117. Personal Communication, D. J. Hagerty, University of Louisville, to C. J. Santhanam, Arthur D. Little, Inc., 1979.

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16. ABSTRACT The report, the fifth of five volumes, focuses on disposal of coal ash and FGD wastes which (together) comprise FGC wastes. Disposal of these wastes represents significant sources of environmental pollution unless proper disposal technologies are employed. Continued R and D efforts have provided substantial baseline information on environmentally sound disposal methods. The report assesses the various options for the disposal of FGC wastes with emphasis on disposal on land. A number of technical, economic, and regulatory factors appear to encourage increasing use of dry disposal methods. Regulatory considerations impacting FGC waste disposal are assessed. Regulations under the Resource Conservation and Recovery Act, the major Federal legislation impacting FGC waste disposal, are still emerging. An assessment of the monitoring requirements from the viewpoints of regulation and environmental control is reported. Ongoing studies on the economics of FGC waste disposal are reported and assessed. Cost estimates for sound disposal practice are $9 to $15 per dry metric ton of waste. Environmental impact issues concerning disposal options include physical stability, public policy and land use, and leachate mobility. A summary of data gaps and research needs in this area are outlined.

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Coal	Flue Gases	Stationary Sources	21D	
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Assessments	Ashes		14B	
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